FINDING COLLABORATIVE INNOVATION NETWORKS THROUGH CORRELATING PERFORMANCE WITH SOCIAL NETWORK STRUCTURE

PETER A. GLOOR[1]*, MARIA PAASIVAARA[2], DETLEF SCHODER[3], PAUL WILLEMS[3]
[1]MIT
[2]HELSINKI UNIVERSITY OF TECHNOLOGY
[3]UNIVERSITY OF COLOGNE
*PGLOOR@MIT.EDU

This paper contributes to the ongoing stream of research correlating social network structure with individual and organizational performance. While teaching a course on optimizing online communication behavior and social network analysis, we collected preliminary data on the relationship between dynamic social network structures and individual and team performance. Students from Helsinki University of Technology and University of Cologne who had never met face to face formed virtual interdisciplinary teams collaborating on a common task, the communication analysis of online communities. As part of their task students correlated performance of the community they were analyzing with social network structure. In this research we compare social network structure and individual and team performance of participants in a multi-user online computer game with social network structure and performance among the student teams. While among computer gamers number of communication links predicts performance, a balanced contribution index predicts performance of the student knowledge worker teams. We also give general recommendations for efficient virtual communication behavior.

Keywords: Social Network Analysis, Performance Measurement, Collaborative Innovation Networks, TeCFlow, contribution index

1. Introduction

The advent of the Internet has provided new opportunities for collaboration thought impossible just a few years ago. Exchanging ideas and work by e-mail, chat, Internet telephony, blogs, and Wikis has opened up new avenues for spontaneous communication. Researchers have begun to study how these new communication channels influence productivity and creativity of virtual teams (Cross 2004, Cummings & Cross 2003, Gloor 2003, Kidane & Gloor 2005, Leenders et al. 2003, Lueg & Fisher 2003). In previous work we introduced Collaborative Innovation Networks, or COINs (Gloor 2006). COINs are virtual teams of self-motivated people with a collective vision, enabled by technology to collaborate in achieving a common goal – an innovation – by sharing ideas, information, and work. In other previous work we have extended well-known measures of social network structure such as degree and betweenness centrality (Wasserman & Faust 1994) with a new measure geared towards measuring virtual interaction in smaller groups – the contribution index (Gloor et. al. 2003).

This paper describes early results on how to improve online communication and social network structure for better performance and creativity. Most of the studies in the context of network structure and performance report a positive relationship between degree centrality and performance at an individual (e.g. Bulkley et al. 2006) and at a group level (e.g. Tsai 2001). Baldwin and Bedell (1997) found a positive correlation between actor centrality and performance in friendship networks and communication networks, while a negative correlation was apparent in advice networks.

Our insights have been gained while teaching a graduate-level distributed course on online collaboration co-located at three universities. The main objective of this course had been to offer students an opportunity to improve their own communication behavior when collaborating in virtual teams to become better members of COINs. They did this by completing an innovation-centered distributed project as a virtual team, and then correlating their individual and team communication patterns with individual and team performance in the distributed project. The distributed project consisted of analyzing a distributed virtual community. To analyze small team interactions, the “contribution index” was used as a measure for the degree of balanced communication and as an indicator for network structure. As a consequence, both online behavior patterns and in- and outgoing actor communication are analyzed. Eventually, this paper provides insights in state of the art digital collaboration dynamics and correlates appropriate structural measures with network performance

In fall 2005 we jointly taught a course to 13 students in Finland and 12 students in Germany on how to optimize their online communication behavior to become better net citizens and members of virtual teams, increasing their efficiency and creativity. Part of the course was taught from MIT, such that the course was distributed at three locations. Figure 1 illustrates the classroom teaching part of the course, where one virtual classroom was formed by participants from Helsinki, Cologne, and Boston.

Figure 1 – Snapshots from teaching the course

Our course was organized in three parts. In part one, students learned about principles of social network analysis (SNA) (Wasserman & Faust, 1994), Collaborative Innovation Networks (COINs), and Swarm Creativity (Gloor, 2006). In the second part students formed seven interdisciplinary teams comprising three to four students from different institutions (University of Cologne, Helsinki University of Technology) and applied the tools framework taught in part one by analyzing a virtual online community. This permitted them to study rules of optimized online communication in other online communities. It also permitted them to identify social networking structures of high-performing teams. In part three the students analyzed the communication behavior of their own virtual team, based on their online communication record of e-mail, chat, and phone interaction. Communication records were collected by e-mailing copies of all communication activities to seven dummy e-mail addresses.

The main goals of the course were to teach students how to be efficient online-communicators and collaborators in distributed virtual teams. Our objective was for students to become more effective communicators by becoming aware of their social position and their contribution pattern in the virtual team. In more general terms, course participants also learned to increase organizational innovation and effectiveness by converting organizations into "Collaborative Innovation Networks" (COINs). On a technical level, they learned how to apply social network analysis using the tool TeCFlow (Temporal Communication Flow Optimizer) developed at MIT and Dartmouth (Gloor & Zhao, 2004).

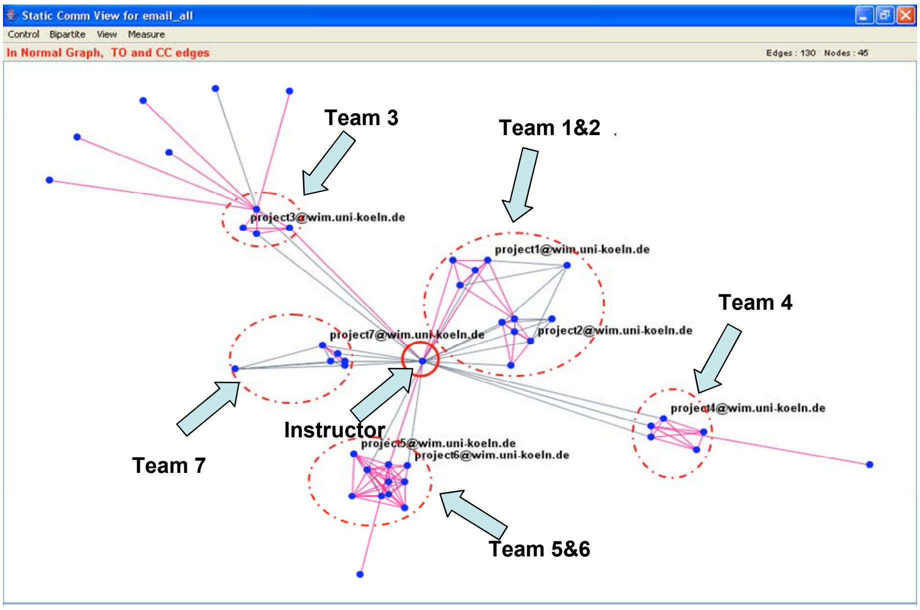

Figure 2 – Communication patterns of project teams in phase 2.

Figure 2 shows the social network during part two of the course, produced with TeCFlow. Ties between actors have been produced by mining the e-mail archive of the course communication. Note the central role of the instructor, with very little inter-team communication. Only teams 1 and 2, and teams 5 and 6 show inter-team communication.

2. The Collaborative Innovation Network (COIN) Framework

In our course we have been trying to make the students better members of online cyberteams. We call such online virtual communities "Collaborative Innovation Networks" (COINs) (Gloor, 2006). Our work generalizes what Peters (1983) calls "skunkworks" and Leavitt and Lipman-Blumen (1995) describe as "Hot Groups". Collaborative Innovation Networks lead to a new approach to innovation and the management of creative groups, resulting in more communicative, collaborative and innovative organizations. It has been shown that for certain tasks, COIN-enabled organizations demonstrate more efficient leadership, culture, structure, and business processes (Gloor, 2006).

The diffusion of innovation in collaborative knowledge networks follows a "ripple effect." Collaborative Innovation Networks (COINs) are at the center of a set of concentric communities, where each community is included in the subsequent, larger community. The dissemination of new ideas in online communities is very similar to the ripple effect when a pebble drops into water. Innovations ripple from the innermost COIN circle to the next larger Collaborative Learning Network (CLN) circle, and then to the surrounding Collaborative Interest Network (CIN) community.

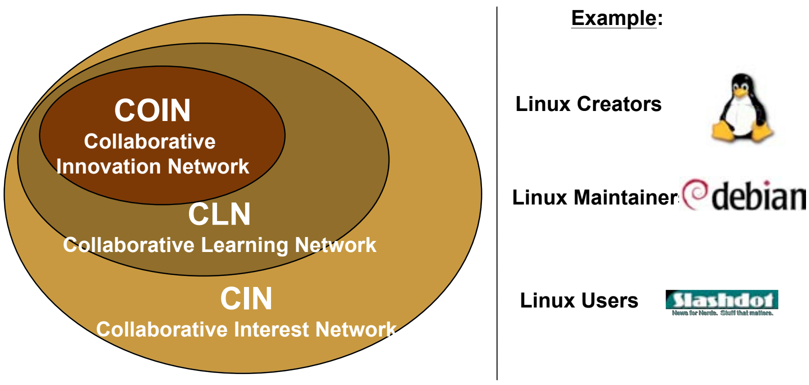

Figure 3. The ripple effect of COIN-based innovation diffusion

Figure 3 illustrates the ripple effect of COIN-based innovation diffusion by the example of the Linux Open Source developers.

We are aiming to distinguish temporal communication patterns typical of these different types of online communities. These online communities are core/periphery structures (Borgatti & Everett, 1999) with small world properties (Watts, 1999). They consist of a central cluster of people, the core team, forming a high-density network with low group betweenness centrality (GBC). The external part is a network forming a ring around the core team. It has comparatively low density, but high group betweenness centrality, thanks to the central core team. The actors in the outer ring (CLN/CIN) have a low betweenness, as they are only connected to core team members, but not among themselves.

As COINs are highly productive engines of innovation, it is of high interest how they can be made more active and innovative (Gloor, 2006). In this paper we describe insights into the functioning of COINs gained while teaching the above-mentioned course. In our subsequent analysis we identify COINs by their core/periphery property, and by a social network cluster of high betweenness embedded into a low-density network.

3. Identifying High-performing players of the online Game "Oceancontrol"

The course participants formed seven separate project teams, each with team members from both Cologne and Helsinki. Each team analyzed an online community. They choose subjects such as communication among contributors to Wikinews, tracking of trends on RFID through using the ISIWeb literature database or analyzing e-mail communication among Enron employees. As the team members were geographically distributed, their communication was conducted online, mostly by e-mail.

One of the most interesting communities to analyze was the group of online gamers of "Oceancontrol," a quite popular online strategy game. The Oceancontrol gaming community consists of about 2000 players. The goal of each player is to manage their own islands, controlling resources and building up troops to conquer neighboring islands. To succeed, players have to form alliances. The more successful a player is, the more experience points she or he gets. Players communicate with each other through an in-game messaging system. "Oceancontrol" was written by Marius Cramer, one of the students participating in our course. This was a fortunate coincidence for this project, as it gave this student easy access to the player data, and also permitted him to contact players directly for interviews.

In the first step the students investigated the communication structure of the player community. They did this by loading the contents of the in-game messaging system into TeCFlow. As figure 4 illustrates, they were able to clearly identify the alliances between the actors through automated social network analysis.

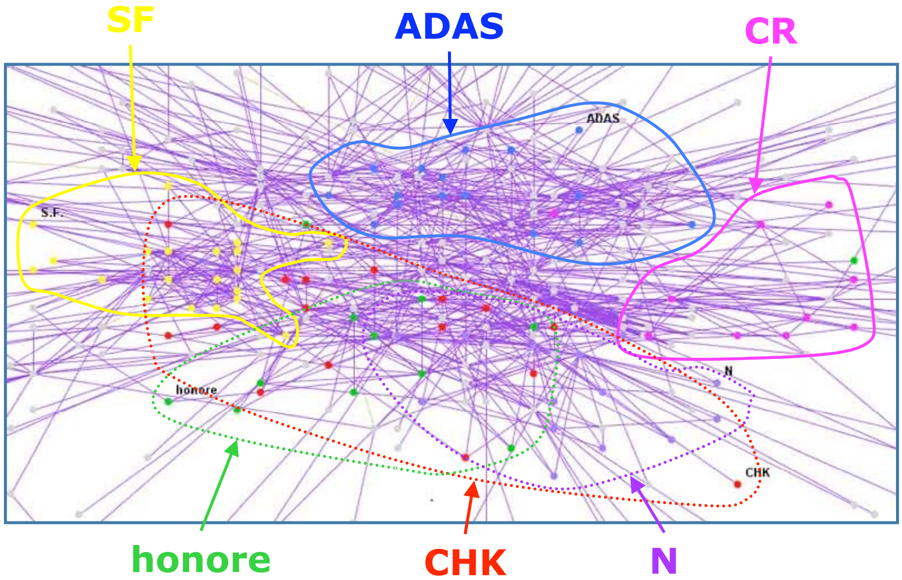

Figure 4 - Alliances as social networks in the Oceancontrol online game

Figure 4 illustrates that members of an alliance mostly communicate with other members of their alliance. This means that alliances are clearly recognizable as clusters. The students then correlated success of the alliance with the position of the alliance cluster in the overall network. As a measure of success players can collect experience points. The more experience points a player has, the higher her/his ranking in the game. The success of an alliance is measured as the average of the experience points of all members.

What the students found is that the success of an alliance was directly correlated with the degree centrality of its members. I.e. the more the members of an alliance communicated, the higher the success of the alliance.

Next the students looked at what made individual players successful. What they found is that a player's success is directly correlated to her/his degree, that is to the absolute number of direct communication partners, and the absolute number of messages that a player sends and receives. It seems that a "balanced" communication behavior, where a player sends and receives approximately the same number of messages is a further, although weaker indicator of success.

In a somewhat surprising result, the students also discovered that the number of communication partners matters more than absolute number of communications – for this game it is better to have many loose communication partners than a few close ones.

The students verified their theoretical results by sending out an online-survey to the players. They found that the players had intuitively come to the same conclusions. For instance, 90% of the players thought that communicating a lot within an alliance would make the alliance more successful. Even more interestingly, 70% of the players reported that they chose new alliance members by their communication skills, while only 4% of the players chose new allies by their success in the game. This ties in well with work by Tiziana Casciaro (Casciaro & Sousa 2005), who found that co-workers rather work with “lovable fools”, than with “competent jerks”. It pays to be a good communicator!

The student team therefore empirically verified what was taught in the course. The first insight is that just by looking at the social network structure, one can discover the teams (the “alliances” in this example). The second insight is that for a team (a COIN) to be successful, it pays to talk with other teams. The most successful teams are embedded in a network of other teams. The third insight is that the more friends a player (COIN member) has, the more successful they will be. While it helps to have a few strong links to other players, strength of relationship is secondary to the number of links. The most successful players have a large network of friends, are embedded in different alliances, and send and receive a lot of messages – this is somewhat different from what we found when comparing social networking patterns and performance of the knowledge worker student teams.

4. Correlating Performance with Social Network Structure

After the teamwork analyzing the online communities was completed, the students looked at their own communication behavior. Each student graded the quality of the work of the teams other than her or his own team on a scale from 1 to 4, with 1 being the best grade. The quality of the work of each team was ranked based on the quality of the final presentation of the team and the final report. Students also ranked the quality of the individual contribution of their own team members. This means that each student gave a grade to each of the

other six teams, and to the two to three peers within the team. The best students and teams were rated 1, the worst a team was rated by a student was 3, the worst an individual was rated was a 4. From these peer ratings we derived two figures for each team, an average external rating based on the result of the team's work and an average internal rating as an indicator of the peers perception of their cooperation.
Three hypotheses were tested based on the average peer ratings. The three hypotheses are:

1. The internal (ingroup) team ratings are correlated to the communication balance of the teams.
2. The external team ratings are correlated to the communication balance of the teams.
3. There is a significant correlation between the external ranking of each team's output and the mutual internal ranking among team members.[1]

We also looked at more simple parameters such as the number of e-mails sent within each team. While there was indeed correlation between external rating and numbers of messages exchanged, it turned out not to be significant. This may be because of the small size of our sample. Applying typical SNA measures such as betweenness and degree centrality [Was94] did not make sense here, because of the small individual team size of three to four members, which were all fully connected.

The hypotheses were tested on the communication data collected from the course and the grades. All e-mail communication between the course participants was collected and was used as the basis for the communication analysis. The main measure to be used for this analysis was the contribution index, which is defined as:

$$\boxed{contribution\_index = \frac{messages\_sent - messages\_received}{messages\_sent + messages\_received}}$$ (Gloor et. al., 03)

The contribution index takes on values between –1 and +1, it is +1 if a person only sends messages and –1 if it only receives messages. A contribution index of 0 indicates a totally balanced communication behavior. The contribution index is a relative and peer specific measure, which can be computed for different timeframes like e.g. 1 or 5 days.

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[1]Tested by Lutz Tegethoff, Ilkka Lyytinen and Sebastian Schiefer during part three of the COIN course

Average weighted variance of the contribution index (awvci)

$$awvci^{ws}(team) = \frac{\sum_{i=1}^{T} m_i \cdot \mathrm{var}(C_i^{ws})}{\sum_{i=1}^{T} m_i}$$

m_i = number of edges on day i

ws = window size

$C_i^{ws} = \left(ci_{i,1}^{ws}, \cdots, ci_{i,N}^{ws}\right)$ = vector of contribution indexes of all team members for day i

$ci_{i,n}^{ws}$ = contribution index of member n on day i

Figure 5 – Average weighted variance of contribution index to calculate the balanced'ness of a team's communication

To capture the balance of a team's communication during a project in a single variable, it is important to factor in the contribution of the peers at each given day, as well as the importance of that day in the context of the whole project communication. To represent all this, the average weighted variance of the contribution index (figure 5) was defined. The window size denotes the sliding time window in number of days used to calculate the contribution index with TeCFlow. In order to reduce the impact of high variances of the contribution index caused by single messages by one member in phases of general low activity, which would lead to distorting (weekend) peaks, the variances are weighted with the number of total edges on that particular day. This weighting increases the influence of patterns that appear in high activity phases such as shortly before the deadlines. The resulting average weighted variance of the contribution index (*awvci*) adopts values close to 0 if the communication is balanced.

4.1 A 'balanced' internal communication does not necessarily lead to a higher mutual assessment

The average internal ratings can be seen as a self-assessment of a team. The expectation was that short response times on mails and equal contribution, which are implied by a low awvci, would improve the mutual ratings in a team.

As it turns out, there was no significant correlation between balanced internal communication behavior and internal rating[2] (see Table 1). We can speculate that team members differed in their

[2] There was no correlation between individual grade and contribution index neither.

willingness to give each other "harsh" grades, thus distorting the measurements in our small sample.

n=7 teams	*awvci*			
	Window Size 1		Window Size 5	
	Pearson Correlation	P-Value	Pearson Correlation	P-Value
External Rating	0.724	0.066	0.921	0.003
Average Internal Rating	0.187	0.688	0.494	0.260

Table 1 – Correlation between ratings and *awvci*

We calculated *awvci* for window sizes of 1 and 5 days. With a time window of 1 day, contribution index values, which form the basis for *awvci,* fluctuate too much. A Window size of 5 days gives better results, smoothing peaks of activity and inactivity periods. It corresponds to a 5-day work-week and fits well into the overall project period of one month.

4.2 A 'balanced' internal communication leads to a better external rating

In this case the correlation between the *awvci* and the ratings is high (see Table 1). The external ratings show a higher correlation with the balance of the team's communications than the internal ratings. It can be assumed that external ratings are more honest than the internal ones as students are not asked to rate team members they have been working with closely for a few weeks. They are more precise too, as they are based on a larger number of judgments.

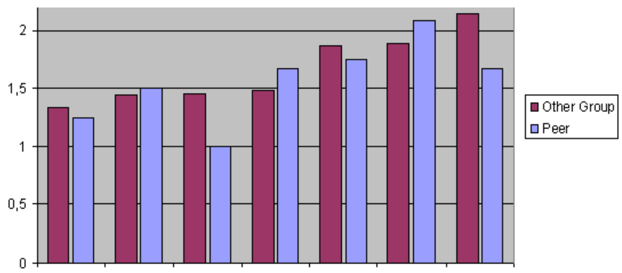

Figure 6 – Ingroup and external (other groups) ratings of 7 teams (low is better)

4.3 Internal (ingroup) evaluation and external (by other group) ratings are correlated

The better the external team rating, the better the average internal rating of the team (Pearson Correlation=0.651; P-Value=0.113; n=7). A satisfied team gives good mutual ratings and provides work of good quality. This shows again that efficient teamwork has a positive impact on results (figure 6).

4.4 Limitations

While these early results are promising, they have to be taken with more than a grain of salt. The used dataset is small and somewhat incomplete. Communication was not completely recorded when it went through channels different from e-mail. Some teams sent messages to their team e-mail address to record these interactions, others did not. Ratings were done on a subjective basis with an underlying rigid structure. Also, our emphasis on temporal balance of contribution index only captures a subset of all communication activities.

5. Challenges of Virtual Collaboration

The student groups faced several challenges during their virtual collaboration, which they reported at the end of the course. The students had not met each other face-to-face across countries, thus they did not know each other or their working styles, which caused some confusion and also getting a sense of "team work" was felt hard to achieve. The beginning was clearly the most difficult phase for many groups, it seemed to be quite hard to start an efficient work process and it took some time before a productive working mode was achieved.

The student groups were formed during a videoconference session: the students joined the groups according to their interest on suggested topics. The only rule for forming groups was that all the groups should have students from both countries. If a group had at least two students from the same country, this led to the formation of co-located sub-groups that at least partly communicated through other means than electronic (e.g., phone or face-to-face), thus this communication was not recorded and other group members could not follow it. Especially for groups having only a one-student sub-group in the other country, this caused difficulties for the isolated student to follow activities in the other country. Even though e-mail was the main communication medium, some groups started to use Skype (contains both chat and voice) or other chat programs especially for coordinating the work and making decisions. The synchronous communication was regarded as very efficient, but the problem was to find meeting dates suitable to all group members, since the students had many other courses at the same time. This problem often led to Skype or chat sessions between only two members at the time.

E-mail communication functioned quite well, but it was regarded as a less efficient communication medium than Skype or chat, since it was slow and thus not very interactive. Especially decision making was felt to be difficult through e-mail. Moreover, the asynchronicity of e-mail communication created uncertainty when others did not know how to interpret the silence of the non-responding team member. Interpreting the sent e-mail messages was not always easy, neither. Translating from “Finnish” English to “German” English and vice versa opened up room for wide interpretation!

Despite these challenges the student groups did very good work and gained interesting results from the analysis of both the on-line communities and their own communication. The student feedback was very positive – the students felt that despite of the problems they had learned a lot.

6. Lessons Learned for Virtual Collaboration

By organizing this course we learned a lot both regarding the arrangements of a distributed course and regarding data collection for research purposes. In the beginning of the course we did not give the students much advice on how to communicate or how to record the communication. We just asked the students to send a copy of all e-mails to an e-mail-box where all the communication of each group would be archived to be used when analyzing communication during their second assignment. We also offered MediaWiki as a forum for discussions. We learned that in the future it might be beneficial to teach in the beginning of the course some rules about how to work and communicate efficiently in a distributed team. In this course the students had to figure it out by themselves and make all the mistakes first, which of course took time away from working on the projects.

Since the student groups found Skype and chat very useful, we will need to encourage use of this kind of communication channel in the future. Moreover, a way to systematically record this kind of communication should be designed and taught to the students. Even though there was active communication inside the groups, the communication across the groups was very limited and took mainly place in connection with class videoconference sessions. Encouraging communication across groups will be needed, e.g. for solving technical problems. For instance, a discussion forum for technical communication problems could be started. Questions to the teachers could be directed to this forum, allowing everybody to follow and participate in these discussions.

The country-specific sub-groups were the reason that not all communication was recorded, e.g. phone calls and face-to-face conversations. This communication was often invisible to other team members, causing problems especially to one-person country-specific sub-groups, when he or she was to a certain extent left outside of the team. This posed additional problems for our communication research setup. This problem could be solved either by forming more balanced groups (at least two persons from one country), advising the students to record the non-electronic communication and informing the others, or by choosing only one team member from each site and organizing the course across several sites. This later solution is what we plan for a next version of this course: to involve four universities, which means four participating sites. That kind of a course would be both more challenging to organize and more challenging for the students to work in, when the groups are highly distributed. However, it would also be more interesting both for the students and for studying the communication patterns. Moreover, all the communication across these sites would be electronic and thus easier to record and for other team members to follow.

7. Industrial Applicability

The insights gained in this project have direct industrial applicability. Fostering Collaborative Innovation Networks leads to direct strategic advantages for knowledge intensive organizations. Consulting firms, software development projects, project management of large projects, mergers and acquisitions, and sales force optimizations are some organizational settings where COINs are ideally suited to improve organizational creativity, quality, and effectiveness. In our analysis we found that while “there can’t be enough communication” for simple tasks – such as in the “Oceancontrol” strategy game, a balanced contribution index might be indicative of teams of high performing knowledge workers for more complex tasks. In this section we will describe some scenarios, supported by actual examples, which describe how COINs might be applied in a commercial environment.

7.1 Getting the Strategic Value from Mergers & Acquisitions

In a merger & acquisition scenario, getting knowledge workers from different companies with different company cultures to form new high-performing teams can be a real challenge.

When a global car manufacturer decided to reengineer the global car parts procurement process, it quickly developed into a much larger project (Gloor, 2006). Turning the entire business model of procurement upside down by creating a multi-tier online marketplace of car-parts-suppliers unleashed tremendous value for the enterprise. The procurement re-engineering team operated as a true COIN, creating the new solution as a collaborative team, and collaborating in a highly efficient small world networking structure with the senior project members acting as hubs of trust. The team members applied the same principles as we identified in our analysis of online communities described above.

7.2 Optimize Research & Development

Research and development organizations can expect substantial advantages when redesigning their knowledge flow so that it operates as a network of COINs embedded into an ecosystem of virtual communities. When developing a new service offering for a global consulting company, an innovative new product was developed by a COIN, which was recruiting new members from its surrounding learning communities while using its global interest community as a sounding board and sales and marketing network (Gloor 2006).

7.3 Streamlining Project Management

Monitoring project management communication for better quality of project output results in substantial savings. Among other benefits, the COIN approach greatly reduces communication failures among project members. It converts one-way communication into two-way dialogues. It discovers core contributors as well as lurkers. Changing project culture to a COIN-based approach makes the team work together more efficiently, unlocking the creative potential of team members. Visualizing knowledge flow will also assist in finding good ideas within the organization.

7.4 Improve the Sales Process

COINs can also improve efficiency and productivity of sales and marketing. Social network analysis gives indications of productive as well as unproductive members of the sales and marketing force. (Bulkley & Van Alstyne 2004) demonstrated that high performing sales force members communicate more with external people than average or low performers. They also showed that high performers make more use of communication technologies for their work. Surprisingly they found that there is no correlation between performance and overall volume of communication. This means that very active communicators are not necessarily high performers. This corresponds well with our insights, that high communication volume corresponds to better execution of simple tasks, while more complex metrics such as low variance in contribution index are better indicators of high performing knowledge workers in complex tasks.

8. Conclusions

In this paper we presented our experience organizing a novel course on optimizing online communication behavior. The distributed student teams applied social network analysis to analyze communication behavior both in a chosen online forum and afterwards inside their own group. We obtained preliminary results on correlating temporal online communication patterns with team performance for both online strategy gaming communities and for more complex knowledge work. Our results based on student peer-evaluation indicate that students in teams exhibiting balanced communication behavior performed best. Students used the insights they gained on the correlation of their own communication behavior with their group performance to improve their future communication behavior and collaboration style in COINs.

We have applied the COIN framework, a well-defined typology of social networks. Our aim was to form COINs, monitor their communication, measure their performance and then correlate the results to gain further insights on communication-related success factors of virtual collaboration. COINs were ‘implemented’ in this case primarily through peer-driven creation of the student teams. Furthermore, getting the students on a common skill-set level (SNA, TeCFlow) led to higher comparability of the results. The premise of the COIN framework is the exceptional quality of COIN-based work, our implementation gave (qualitative) proof for that. Our (quantitative) analysis suggests guidelines for further improvement of COINs and a new metric to measure high-performing COINs.

The presented communication analysis can only be considered indicative, as not all the communication was documented and as there were problems in the data recording. Despite these weaknesses, this experiment can be regarded as successful: the student feedback was very positive and we gained valuable insights for (1) improving the course (2) efficient virtual collaboration, and for (3) measuring the performance of knowledge workers in COINs. Based on this experience we are currently teaching the course again, further extending the feedback loop on refining our methodology for practical applicability of COINs. We would like to close with a quote from a student commenting on the course:

"This course was a great one. We learned a lot of things. The most valuable thing I learned was that the better communication is, the more successful you are (personally or as a team)."

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