ANALYSIS OF INTERPROFESSIONAL COLLABORATION IN AN ONLINE LEARNING ENVIRONMENT USING SELF-ORGANIZING MAPS

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ABSTRACT

This exploratory paper uses the Self-Organizing Map (SOM) algorithm to analyze the online collaborative discourses of an interprofessional team (N=23) of hospital workers engaged in an 18-month reflective practice and continuous learning project. Interprofessional practice is an emerging best practice model in health care internationally. However, there is very little research investigating the usefulness of online environments for supporting such practice, or the nature of effective online interprofessional collaboration. Preliminary results demonstrate unique characteristics of the participant group's s interactivity that would otherwise remain unidentified using conventional quantitative methods of discourse analysis. The SOM analysis generated a relational profile of participants' reading and linking activity in an online learning environment that not only captures the emergent dynamics of interprofessional collaboration over time, but also highlights individual differences within and between professional groups. A central conclusion is that there is a high degree of within and between group variability as measured by interprofessional activity patterns. In general, we provide a framework for using the Self-Organizing Map method in the analysis of online interprofessional and socio- cognitive activity.

1. INTRODUCTION

Over the past decade, interprofessional collaboration has emerged as the best practice model in health care education and practice internationally (Barr et al. 1999; Leathard 2003; Rachlis 2004; Romanow 2002; Zwarenstein and Reeves 2002; Zwarenstein et al. 2001). There are many terms used interchangeably to describe interprofessional collaboration ranging from multidisciplinary, multiprofessional, trans-professional, inter- and intra-disciplinary, transdisciplinary, etc. (see Bruun and Toppinen, in press, for an in- depth review of interdisciplinary practice; and Leathard 2003 for a review of keywords used to describe inteprofessional work and learning).

Generally, interprofessional collaboration in practice settings refers to a team of professionals coming together to engage in interactive learning (Barr, 1994; Leathard, 2003). Some impediments to effective interprofessional collaboration in health care include status and labour divisions between professions (Loxley 1997; Russell 2002), lack of coordinated activity within and between professions and agencies (Engeström et al. 2003) and poor communication (Mariano 1999). Ideally, interprofessional collaboration results in increased staff efficiency, effective service provision and patient care and a more satisfying work environment (McGrath 1991).

There has been relatively little research concerning the use of online or computer technologies to support interprofessional learning, collaboration and practice in health (Reeves and Freeth 2003), and more specifically, continuous professional development at the workplace (Barnes and Friedman 2003).

Design experimentation is an emerging methodology in the learning sciences' community (Bereiter 2002a; Brown 1992; Collins 1999; diSessa and Cobb 2004; Edelson 2002; Fishman et al. 2004). Collins (1999, pp. 290-293) identified seven main differences between traditional experimental design versus design experiment methodology presented in the following dichotomies, the latter characterizing design research: 1) laboratory settings versus messy situations, 2) a single dependent variable versus multiple dependent variables, 3) controlling variables versus characterizing the situation, 4) fixed procedures versus flexible design revision, 5) social isolation versus social interaction, 6) testing hypotheses versus developing a profile, and 7) experimenter versus co-participant design and analysis.

Design research methodology is used to design, sustain and evaluate knowledge building communities (Bereiter 2002b; Scardamalia 2003a, 2003b). Knowledge build-

ing is a pedagogical approach whose roots are found in the CSCL (Computer Supported Collaborative Learning) community. Knowledge building pedagogy extends the boundary of learning from an individual to a collective enterprise. The main activity of participants engaged in knowledge building is collaborative problem solving and advancement of both individual and collective knowledge. Knowledge building is closely aligned with theories of distributed cognition (Cole and Engeström 1993; Solomon 1993), expansive learning (Engeström, 1987, 1999), and networked expertise (Hakkarainen et al. 2004b).

This paper presents analysis of data collected from a knowledge building design experiment conducted in a Canadian hospital (Russell et al. 2002). The purpose of the design experiment was to use Knowledge Forum as a medium to support reflective practice (Schön 1983, 1987) and interprofessional knowledge building among a team of hospital-based health care workers. Knowledge Forum databases contain a wide array of participant constructed data. Each database is unique depending on the purpose of community engagement and like most design research the emergent data sets are multi-dimensional and complex.

We used a data mining approach to analyze the data set. Data mining is the process of analyzing data from different perspectives and summarizing it into useful information (see e.g. Hand et al. 2001). There are a number of different techniques for data mining including, but not limited to, rule induction and data visualization. We used the Self-Organizing Map (Kohonen 2001), a method widely used to analyze and visualize complex data. Originally considered an artificial neural network model, the SOM is more commonly used now as a general-purpose statistical tool to deal with data when the relationships between variables are complex.

The concept of emergence is often associated with the SOM as it is able to sort the data in such a way that the main relationships between the cases and the variables are revealed. Moreover, the SOM automatically creates a certain kind of "landscape" based on the input data. The landscape is actually a two-dimensional lattice called the map. The original multidimensional data is projected on the map. We used the SOM analysis to characterize the emergence of interprofessional collaboration from an activity perspective.

In the first study, we applied the SOM in a similar manner used by Honkela et al. (2000a) in which a number of sociological and life-style variables were analyzed. In the second study, we applied the SOM as a means for conducting a kind of *relational profiling* of interprofessional collaboration. Analysis focused on three aspects of online interprofessional activity: 1) collective knowledge building as measured by basic knowledge building indicators; 2) emergent interprofessional collaboration as measured by reading and linking activity, and 3) profession specific analysis of collaborative activity as measured by reading and linking activity.

This paper builds on additional research conducted by Honkela et al. (2000b) that proposed to integrate CSILE and SOM to provide more robust constructivist learning environments. Although exploratory, we consider this paper a first step towards such integration.

2. DATA AND METHODS

Data for this paper comes from a longitudinal study of an occupational sample of Canadian hospital workers gathered 1999 to 2001. In the following section we describe the data in more detail. We conclude by describing the methods used for analysis.

2.1. Participants

Participants (N=23) in this study were all members of the Professional Practice Portfolio at the Toronto Rehabilitation Institute (Toronto Rehab), a regional health care facility in Ontario, Canada. Participants came from four of the five hospital sites and worked in all six specialty clinical inpatient and outpatient programs including: cardiac and secondary prevention, complex continuing care, geriatrics, musculoskeletal, neurorehabilitation, and spinal cord injury. This interprofessional team included the following professional groupings: clinical nurse specialists (n=10), clinical nurse educators (n=4), occupational therapists (n=2), physiotherapists (n=2), interns (n=2), manager, bioethicisist and researcher.

2.2. Duration

The majority of participants (n=14) engaged in an online reflective practice and continuous learning project for 18-months (November 1999 to May 2001). Nine participants varied with respect to duration ranging from a minimum of four to a maximum of 10 month durations.

2.3. Technology

The online collaborative learning environment used in this project was Knowledge Forum®, a second-generation computer supported intentional learning environment (CSILE). Knowledge Forum may be accessed using a web browser or by using the Knowledge Forum Client. The server runs on Linux, Windows and Macintosh operating systems. Participants in this study used client version 3.2.

The functions and features of the database software support online discourse, collaboration and problem solving. Views are shared workspaces in which participants contribute notes.

2.4. Online collaborative activity

The content of any Knowledge Forum database is entirely the construction of participants. Over the period of investigation, participants wrote and contributed approximately 1,500 notes and created 115 views or communal workspaces. The main activity in the database was a monthly reflective practice activity called *Monthly Reports*. Participants entered reflective notes into a view (communal workspace) about their professional problems, accomplishments and goals. Also, they read each other's notes and engaged in collaborative discourse about shared problems. Participants created new views when problems posed in

the Monthly Reports activity warranted further investigation and collaborative work. A total of 17 Monthly Reports views and 36 emergent problem-solving views were created.

2.5. Analytic Method

An online evaluation tool called the Analytic Toolkit (ATK) (Burtis, 2001) was used to collect frequency data about online interprofessional collaborative activity. First, an analysis of basic measures of activity including notes created, views worked in, problems worked on, revisions and percentage of notes linked, key-worded and read was performed for all participants. Second, an analysis of (1) who read whose notes and of (2) linking behavior that included measures of build-on notes, references, and rise-aboves (collection of notes) was performed for all participants.

All frequency matrices were analyzed using the Self-Organizing Map (SOM) algorithm (Kohonen 2001). The SOM is a means for automatically arranging high-dimensional statistical data. The map attempts to represent all the input with optimal accuracy using a restricted set of models or prototypes. The prototypes become ordered on a map grid so that similar prototypes are close to each other and dissimilar prototypes far from each other. The SOM is useful in clustering, abstraction, and visualization through dimensionality reduction. A map is ordered and it follows the patterns of the input data in a non-linear but generalizing fashion.

In the first part of this study, we have applied the SOM in a similar manner as in (Honkela et al. 2000a) in which a number of sociological and life-style variables were analyzed. In the second study, we apply the SOM as a means for conducting a kind of *Relational Profiling*.

3. RESULTS

The goal of this section is to characterize the emergence interprofessional collaboration and knowledge building from an activity perspective.

3.1. Study 1: Basic collaborative knowledge building activity

Results depicted in Fig. 1 provide a visualization of all subjects' basic collaborative knowledge building activity. Frequency data for the following seven variables served as input data for SOM analysis: (1) number of notes created, (2) percentage of notes linked, (3) percentage of notes with keywords, (4) number of views worked in, (5) number of problems worked in, (6) percentage of notes read, and (7) number of revisions.

The map depicts the relationship between subjects and basic knowledge building variables. Two distinct clusters of subjects appear in the bottom right (n=6) and upper left corners (n=4) of the map, respectively.

The cluster in bottom right corner is comprised of 3 clinical nurse specialists (subjects 15, 19, 16, Group A), an occupational therapist (subject 5, Group D), a physiotherapist (subject 11, Group E) and a nurse intern (subject 52, Group G). The cluster in the upper left corner of the map is comprised of 2 nurse educators (subjects 2 and 12, Group B), an occupational therapist (subject 6, Group D) and a bioethicist (subject 13, Group F). These clusters are distinct from each other with the bottom right cluster exhibiting lower levels of overall activity relative to the cluster in the upper left corner. For example, subjects in the bottom right corner tended to create fewer notes, have low levels of reading and revising notes and worked in less views and on less problems relative to the cluster in the upper left corner who had moderate to high levels of overall knowledge building activity.

Two subjects, the researcher (subject 51, Group H) and a nurse intern (subject 14, Group G) are outliers, exhibiting distinct behavior relative to other subjects and also very different from one another given their spatial distance on the map.

The profile of the nurse intern (subject 14, Group G) is interesting because although she had created very few notes, those notes she created, had extremely high modification rates relative to other subjects. As well, her readership, linking and keywording activity was high relative for example to the cluster in the bottom right corner of the map.

The remaining subject dyads and triads that are distributed throughout the map reveal similarities between subjects. Interestingly, these dyadic and triadic groupings are comprised of mixed professions.

Overall, results indicate within professional group diversity in terms of online collaborative activity. Despite the higher incidence of clinical nurse specialists in the sample, the self-organization successfully captured differences in online activity both within and between professional groups.

In Fig. 2 the basic relationships between the variables are revealed. These variable maps are illustrations of the distribution of the 7 basic knowledge building variables in the map shown in Fig. 1. We can detect a certain correlation, e.g., between the second and the third variable, percentage of notes linked and percentage of keywords. The high values are revealed by the lighter color of circles located in the upper part of maps. On the other hand, the first, fourth, fifth, sixth and seventh variables (notes created, number of views worked in, percentage of notes read, and number of revisions) are all correlated in such a way that the high values of these variables are located in the lower left corner of the map[1]. However, the fifth variable (number of problems worked in) has broader dis-

[1]The psychology researcher and first author of this paper (subject 51, Group H) is located in the lower left corner of the map Fig. 1 and lower right corner of map in Fig. 3. The researcher's profile is clearly different from other participant profiles in overall knowledge building activity and interprofessional collaboration. She exhibited high rates of overall activity and was unique in her reading (100% of all notes read) and modification activity relative to other participants. In design research methodology, researchers are co-participants (Collins, 1999). Therefore we included the researcher in all visualizations. Future analysis will compare visualizations with and without researcher activity in more detail. Overall, the basic organization of the maps is not significantly influenced by the presence of the researcher in the data because the SOM is a non-linear mapping. In contrast, linear analysis of an outlier like this would skew the overall result significantly.

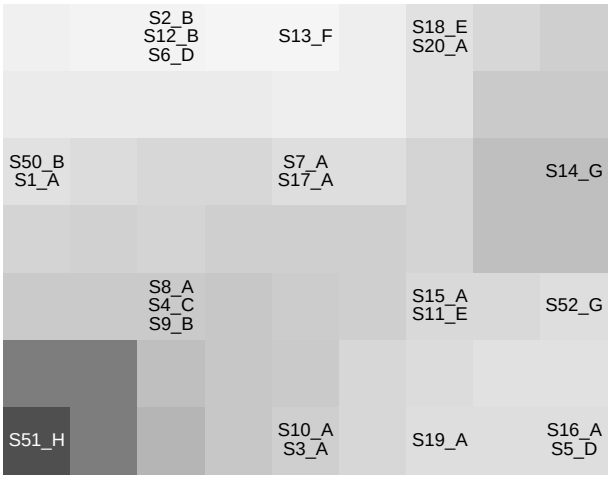

Figure 1. Self-organizing map of basic collaborative knowledge building activity. Subjects with more similar activity profiles tend to be positioned closer to each other on the map. Conversely, the greater the distance between subjects, the less similar are their activity patterns. Each label on the map refers to one subject, showing the index of the person and the professional group to which she belongs: clinical nurse specialist (Group A), nurse educator (Group B), manager (Group C), occupational therapist (Group D), physiotherapist (Group E), bioethicist (Group F), nurse intern (Group G), and psychology researcher (Group H).

tribution of relatively high values on the left side of the map whereas most of the other variables obtain high values in the lower left corner of the map.

In summary, the SOM analyses in Study 1 depict the emergence of collective knowledge building activity over time.

3.2. Study 2: Relational Profile of Interprofessional Collaboration

Results depicted in Fig. 3 provide a visualization of all subjects' reading and linking activity. Frequency data for the following 2 variables served as input data for SOM analysis: 1. reading activity (who read whose notes) 2. linking activity (build on notes, references, notes in rise-aboves)

Results presented in Fig. 3 provide a relational profile of interprofessional collaboration. Whereas Study 1 focused on overall knowledge building activity for all participants, this analysis investigates the relationship between indicators of interprofessional collaboration in more depth by focusing on the way in which professionals communicate and collaborate online. We considered reading and linking activity to be the best indicators of interprofessional collaboration.

Analysis reveals that some subjects bear closer resemblance to each other with respect to reading and linking activity while others are considered outliers and present unique and distinctive patterns of online engagement. Two clusters of participants appear in the upper right and lower

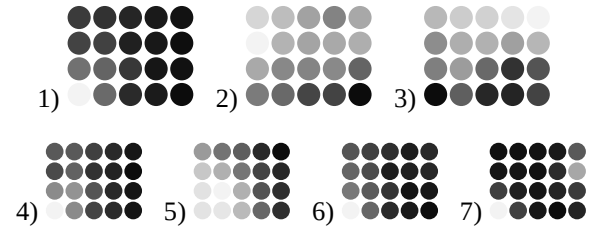

Figure 2. Distribution of the variables used in the analysis of basic knowledge building activity (from the left): 1) number of notes created, 2) percentage of notes linked, 3) percentage of notes with keywords, 4) number of views worked in, 5) number of problems worked in, 6) percentage of notes read, and 7) number of revisions. A light shade of gray denotes a high value of the variable and a dark shade of gray represents a low value.

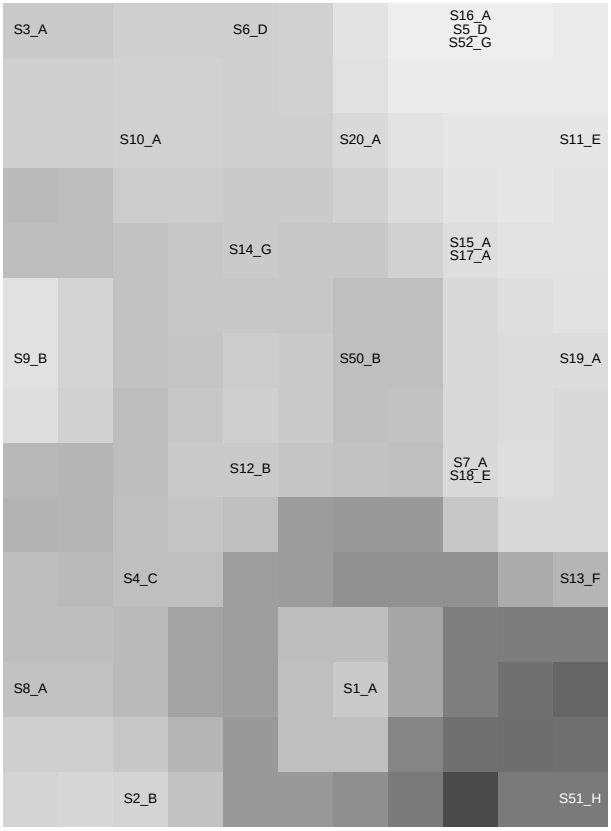

Figure 3. A self-organizing map based on who read whose notes and on the linking activity. Each label on the map refers to one subject, showing the index of the person and the professional group to which she belongs: clinical nurse specialist (Group A), nurse educator (Group B), manager (Group C), occupational therapist (Group D), physiotherapist (Group E), bioethicist (Group F), nurse intern (Group G), and psychology researcher (Group H).

left corners of the map, respectively. The upper right corner contained the largest grouping of subjects (n=10) with similar reading and linking behavior. Six clinical nurse specialists (subjects 7, 15, 16, 17, 19 and 20, Group A), two occupational therapists (subjects 5 and 18, Group D), a physiotherapist (subject 11, Group E) and a nurse-intern (subject 52, Group G) comprised this group. The lower left corner contained the next largest grouping of subjects (n=4) with clinical nurse specialists (subject 8, Group A), two nurse educators (subjects 2 and 12, Group B) and a manager (subjects 4, Group C). Interestingly, both clusters exhibited similar linking activity (moderate levels) but the cluster in the lower left corner's reading activity resembled their linking activity, while the reading activity of the cluster in the upper right corner was low.

Another interesting feature of this map is that the remainder of the subjects (n=8) are distributed in the landscape as autonomous agents. A clinical nurse specialist (subject 1, Group A) and the researcher (subjects 51, Group H) were outliers. Their activity, although more similar to each other, was very different than the overall groups activity profile. These subjects had high rates of reading and linking activity relative to other participants.

Fig. 4 is related to Fig. 3 in a direct way: each position in the small maps corresponds to the same position in the large map (Fig. 3). Each small map indicates how much the other subjects have been linking to (a-c) or reading (d-f) her notes. Altogether there are 46 such small maps and among them we have chosen six representative examples.

Fig. 4 (diagrams a to c) reveals that the occupational therapist (subject 6, Group D) linked to her own notes and was linked to most by the manager (subject 4, Group C). The clinical nurse specialist (subject 8, Group A) linked to herself and was linked to most by another clinical nurse specialist (subject 3, Group A). The clinical nurse educator (subject 12, Group B) received the most linking activity relative to the other two subjects. She linked to herself and was linked to most by the cluster in the lower left corner of the map (Fig. 3) including a clinical nurse specialist (subject 8, Group A), two nurse educators (subjects 2 and 12, Group B) and a manager (subject 4, Group C) and by another clinical nurse educator (subject 50, Group B) and the researcher (subject 51, Group H).

Fig. 4 (diagrams d to f) reveals that all subjects, the occupational therapist (subject 6, Group D), the clinical nurse specialist (subject 8, Group A) and the clinical nurse educator (subject 12, Group B) read their own notes and were read most by the researcher (subject 51, Group H).

4. CONCLUSIONS AND FUTURE DIRECTIONS

A challenge facing design researchers interested in understanding real world practice is that the participant groups under investigation often do not meet the requirements for traditional statistical analysis. For example, in this occupational sample some professional groups had only one or two members while the largest group had ten members. The SOM analysis allowed us to evaluate interprofessional collaboration without needing to segment the sample into professional groupings in advance. As such, the resultant visualizations captured the emergent quality of within and between groups' interprofessional collaboration, as well as the gestalt of collective activity.

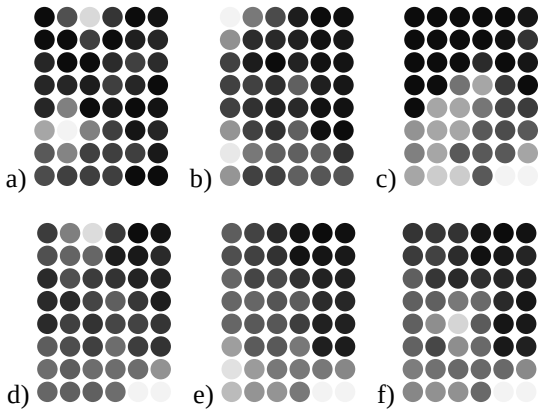

Figure 4. Linking: a) Subject 6 (Group D), b) Subject 8 (Group A), c) Subject 12 (Group B). Reading: d) Subject 6, e) Subject 8, f) Subject 12.

Preliminary SOM analyses reveal a high degree of within and between group variability as measured by interprofessional activity patterns (basic knowledge building measures and reading and linking activity). As well, the SOM visualization captured emergent interprofessional groups by clustering participants on the SOM landscape that exhibited similar behavior.

As potential future directions we can mention (1) richer analysis of interacting quantitative variables, (2) analysis of the textual content of the discourse using text mining methods such as the WEBSOM (Honkela et al. 1998, Lagus et al. 1999), and (3) exploring approaches for more in depth analysis of emergent patterns of leadership, knowledge building, boundary crossing, learning and networked expertise (Hakkarainen et al. 2004), (4) comparing the SOM to other visualisation methods such as social network analysis, etc.

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