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An Application of Social Network Analysis to Knowledge Building

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ABSTRACT

This paper is a design study that explores the use of server log data to guide knowledge building. We use the Analytic Toolkit for Knowledge Forum™ (KF) and techniques from social network analysis to analyze participation and interactivity in two KF databases. In doing so, we connect individual measures on the use of KF features with measures that probe collaboration at a more systemic level. In this, we are attempting to move from a view of assessment that in our view is overly individual (Chan & van Aalst, in press). The first case study is drawn from a grade 4 class studying electricity and First Nations issues; the second study is drawn from a grade 9 class preparing for the International Baccalaureate Program. In each case, the results uncover useful information about participation and interactivity. In the first study, there were correlations between the use of KF features and the social network variables that deteriorated over time; there also was a lack of reciprocity in the interactions. The students in the second study used the features of KF more extensively, which was accompanied by more reciprocity. In that study there were no significant relationships between the use of KF features and the social network variables. We emphasize not the findings of the studies themselves, but argue that analyses like these be used to inform a class's ongoing efforts to improve its knowledge building discourse.

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The goal of this paper is to explore the use of server log data to inform assessment of knowledge building supported by Knowledge Forum (Bereiter & Scardamalia, 1996), particularly the assessment of collaborative practices. An important issue in assessment of CSCL is to tackle the problem of assessing both individual and collective aspects of collaborative knowledge building (Chan & van Aalst, in press). There are also practical and pedagogical problems faced by researchers and teachers in analyzing hundreds or thousands of notes in the databases. This paper examines the use of the assessment tools of Analytic Toolkit for Knowledge Forum (Burtis, 1998) and Social Network Analysis in analyzing server log data from two Knowledge Forum databases. Our focus is not on evaluating the effectiveness of the computer environment or comparing differences across classrooms; rather, our emphasis is placed on assessing knowledge building in ways that can provide useful information for teachers and students for improving their discursive practices. Data are drawn from two illustrative case studies using the knowledge building approach and Knowledge Forum. We first present the approach of knowledge building followed by an explication of the assessment dilemma and assessment techniques. Two case studies are then reported exploring issues related to probing individual and social aspects of knowledge building.

BACKGROUND

Knowledge Building

Bereiter and Scardamalia's knowledge building perspective attempts to make the approaches experts take to new learning more central in education in a variety of settings, including K-12 education, teacher education, and professional development (Bereiter,

2002; Bereiter & Scardamalia, 1996). Recently these authors described the main point of knowledge building as follows:

> … Knowledge building is work on the creation and improvement of ideas. The dynamic is social, resulting in the creation of public knowledge. … Public knowledge can itself become an object of inquiry and the basis for further knowledge building. Thus there is the possibility of a knowledge building dynamic that drives the continual creation and advancement of new knowledge. … (Scardamalia & Bereiter, March 29, 2003)

Bereiter and Scardamalia argue that the core of the knowledge building perspective is a distinction between learning and knowledge building When students are learning, they are acquiring concepts and theories that are already understood by the world at large. When they study a science textbook to understand evolutionary theory they are learning what is already understood by biologists. Within the framework of social constructivism, learning would involve peer interaction, including discussion. When students are knowledge building, by contrast, they are contributing conceptual artifacts to a public discourse. Examples of conceptual artifacts are theories, questions, designs, and proofs. In the public discourse these intellectual artifacts are scrutinized, tested, modified, and put to new uses—they are improved and become understood better by the community engaged in the discourse. Of course, students learn from knowledge building, as they abstract personal understanding from the public discourse. Learning and knowledge building involve the same psychological processes: e.g., students negotiate meaning through conversation, and assimilate and accommodate ideas. They key difference is how students see the purpose of, for example, a discussion. When students

are learning they are (collaboratively) trying to understand an idea, the meaning of which they might view as certain and static; when students are knowledge building they are (collaboratively) trying to improve an idea. Students involved in knowledge building sometimes see themselves as part of a discourse that has in history the main actors in a discipline, a point illustrated by the following quote from a grade six student:

> … Francis Bacon (1561-1626) had a theory. His theory was that heat was motion, nothing else. He thought that the faster the particles in an object moved, the hotter the object was. He was also supported by several other leading scientists in his time. Bacon's theory is also the same as my theory in entry #7. Bacon's theory is now the definition of heat. ("Sean", in van Aalst, 1999, chap. 4)

Scardamalia, Bereiter, and their colleagues have developed computer support for knowledge building, first in CSILE (Computer Supported Intentional Learning Environments), and more recently Knowledge Forum ™ (KF). These computer database systems are designed specifically to support theory improvement. Features in KF designed to support theory development are scaffolds (sentence starters), keywords, note referencing, rise-above notes (used to synthesize the ideas in several notes, "rising" to a higher level of theory), and views (a window that notes are first placed in). Notes can be reused for different purposes by copying short-cuts into different windows to support different purposes or points of view (hence the name "view"). Studies of knowledge building have demonstrated positive effects on literacy, metacognition, depth of understanding, and epistemological sophistication (e.g. Bereiter, 2002; Hakkarainen, 1998; Hewitt, 1996; Oshima, Scardamalia, & Bereiter, 1996; Scardamalia, Bereiter, & Lamon, 1994).

Recent work has focused on the development of some descriptors that represent "best practice" examples of knowledge building discourse. Scardamalia (2002) has developed twelve such descriptors. Van Aalst and Chan have used four "pedagogical knowledge building principles" to scaffold and assess knowledge building portfolios (van Aalst & Chan, under review; Chan, van Aalst, & Lee, 2002): 1) working at the cutting edge; 2) progressive problem solving; 3) collaborative effort; and 4) self-monitoring knowledge. Together these four principles describe social and individual aspects of knowledge building. For example, progressive problem solving is primarily concerned with how the community's ideas are improving over time, whereas self-monitoring has a more personal flavor. For the purpose of this paper, we need to elaborate only on collaborative effort.

Collaborative effort focuses on the importance of working on shared goals and values in developing community knowledge; students display a commitment to help others further the community's knowledge. Van Aalst and Chan (under review) suggest this can be evident at several levels. At the first level, evidence of collaborative effort is evidence that students are writing notes in response to other notes. Students raise questions, extend theories, and provide examples or relevant information. At the second level, students have some awareness that students who may read their notes may be missing contextual information and provide clues to help these students to make sense of the note. For example, students may include scaffolds, link notes to earlier notes, and provide clues in the text of the note. At the third level, students are aware that knowledge construction is possible because students can examine a problem from multiple perspectives, for example by comparing two theories. Consequently, students work systematically to index their

contributions with keywords, scaffolds, and titles to enhance the chance that others will encounter their notes. Students also contribute notes with new lines of thought that other students can develop further. The fourth level describes kinds of community service. At the fourth level students contribute some notes that integrate a number of other notes, for example, summarizing what has been learned about a problem and describing what still remains to be discussed or investigated. In addition, collaborative effort can manifest itself in a variety of activities to maintain collections ("views") of notes. This can range from starting a new view when one seems needed to evaluating what has been learned from the discussion in a view.

Apart from the conceptual problems to be described later in the paper, the assessment of knowledge building is a practical problem. A database might grow by 700 to 1000 notes in a few months. How does a teacher develop a practical knowledge of how the discourse is developing to support the students in their efforts? Teachers who begin with KF often think that they have to read and respond to a large number of notes to develop such knowledge, and quickly find it an overwhelming task. Further, this approach does not often lead to success because teachers are unable to develop adequate conceptual lenses for assessing the progress of the discourse. For knowledge building to be a scalable educational perspective, we suggest, we need to develop tools that teachers and students can use to think about the knowledge building discourse to evaluate to what extent there is knowledge building, what the problems are, and what the possible next steps are for the class.

One partial solution is to use a set of guiding statements that help teachers and students identify aspects of knowledge building discourse. Some teachers ask students to

periodically prepare portfolios based on such statements to capture the class's best examples of knowledge building (Chan, van Aalst, & Lee, 2002; van Aalst & Chan, under review). This technique is still labor intensive but does provide a lens for attempting to improve the class's discursive practices on a time scale of months. In this paper, we are exploring techniques that use information about the use of database features that can be obtained from the KF server. We present two case studies in which we examine such variables as the number of notes contributed, the percentage of notes that are linked, and the percentage of notes read by individual students, as well as data of a more social kind, such as the extent to which notes written by particular students are "built on" (i.e. responded to). Our interest in this paper is primarily in describing some tools to examine the social nature of knowledge building including participation; reciprocity and connectivity; social position, and social interaction. In due time we expect to use qualitative information to work with such quantitative indices to provide a more complete picture. In other words, what server log variables are strong candidates for capturing individual and social aspects of knowledge building? We focus on one aspect of knowledge building—collaborative effort.

Some Current Developments in Assessment in CSCL

We first situate our work in the broader perspective of assessment in CSCL.

Although CSCL environments such as KF offer many possibilities for knowledge building, important questions exist relating to assessment in CSCL. An important issue is the problem of assessing both individual and collective aspects of knowledge advances. Paradigmatic shifts have taken place in theories of learning emphasizing the social,

distributed, and collective nature of learning (Bereiter, 2002; Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Salomon, 1993). Sfard (1998) discussed two main metaphors of learning: knowledge acquisition and participation. From the point of view of the acquisition metaphor learning is a matter of developing concepts or acquiring knowledge. It presumes that learning is a matter of individual construction and acquisition; learners acquire abstract knowledge by abiding by pre-defined or pre-given rules. The focus is on knowledge construction and acquisition as outcomes rather than a process. The participation metaphor, by contrast, suggests that learning is a process of becoming members of a certain community; learners are viewed as persons interested in participation in certain kinds of activities rather than interested in accumulating private ideas. The participation metaphor highlights the role of social community in the knowledge building process (Palonen & Hakkarainen, 2000).

Stahl (2002) posits collaborative knowledge building as a social process of interacting with others, and involving the interplay of group and personal perspectives. Knowledge that can be considered a product of social communication is rooted in the interaction patterns of the communicating societies (Stahl, 2000). In Stahl's study, the learning process is modelled as the mutual constitution of the individual and the social. Knowledge is a socially mediated product. Studies in social psychology suggest ways in which cognition may be related to its social context. According to Pattison (1994), social cognition is to study individuals' mental representations of the social world, and the corresponding social context refers to individual's social position or social role in a social network. Pattison claimed that an individual's position in a social context is related to cognition, because individual's social position plays a part in determining the specific

information to which the individual is exposed. Furthermore, individuals in different social positions receive different information so they may come to construct knowledge differently. The interplay between social position and cognition, according to Pattison, is based on the thesis that a particular social position is associated with certain regular patterns of social interaction. In addition, the association between cognition and social position can be further disclosed by Carley's model (1986a, 1986b), which emphasizes the interaction between social structures (modelled as a network of social relations) and cognitive structures (represented by semantic models of human knowledge). Carley claimed that social interaction is a driving force behind knowledge acquisition. The literature demonstrates, from the perspective of social psychologists, that learning and knowledge acquisition can be investigated by studying individuals' social positions and social interaction in online knowledge building communities. In current CSCL research, social network analyses have been used to capture such aspects of examining students' social positions and interactions in the community (Hakkarainen, Lipponen, Järvelä, & Niemivirta, 1999). This paper extends the analyses integrating information from both SNA and knowledge-building indices from Analytic Toolkit in examining the problems of assessing both individual and social aspects of knowledge building.

THE ANALYTIC TOOLKIT AND SOCIAL NETWORK ANALYSES

Social Network Analysis and CSCL

Server log data can be used to extract considerable information about how students use software such as KF to support a knowledge building discourse. At one level

we can examine how many notes a given students has created, the percentage of notes that are linked to other notes, and so on. At a more interactional level we can examine how students interact with specific other students. For example, who is reading a given students' notes? Whose notes are being read most? Are there students who mediate between other students and therefore have a high degree of "betweenness"? In recent years, relational data have been analyzed by techniques referred to as social network analysis (SNA) to explore such questions (Cho, Sefanone & Gay, 2002; Laat, 2002; Martinez, Dimitriadis, Rubia, Gomez, Garrachon & Marcos, 2002; Palonen & Hakkarainen, 2000).

According to Haythornthwaite (1996), SNA is an approach and set of techniques for the study of information exchange, focuses on patterns of relationships between actors, and examines the availability of resources and the exchange of resources between these actors. Instead of studying the behavior of analytically isolated individuals, social analysts describe patterns of relationships between actors, analyze the structure of these patterns, and seek to uncover their effect on individual behavior. From the point of view of SNA, social structure can be represented as a network in which individuals in a community are represented as nodes, and the interaction among the community members is denoted as set of ties, connecting the nodes. An information relationship refers to what kinds of information are being exchanged between whom, and to what extent. The interaction patterns between actors suggest how information moves in a network, and how actors are positioned to facilitate or control the information flow. For example, who is at the center of the network, and what contribution can the actors who have high centrality (of degree, betweeness, and closeness) make?

The Analytic Toolkit

The Analytic Toolkit is a program developed by the Knowledge Building Research Team (Burtis, 1998) for analyzing server log information; it can provide up to 17 analyses of how students interact with the KF database, see figure 1.

As the figure shows, the analyses fall into six groups: database overview; use of specific features, which are reported in a table with one row for each student, together with summary statistics; specific activity logs that focus on note saves and similar features; relational analysis that show how specific students are interacting with other students; and analyses that show histories of various types. It is possible to use a "code book" instead of the names students use in the database, and upload an ATK report to the database, where it can be discussed by the class and teacher to inform improvement efforts. In this paper we focus on "Basic Knowledge building Measures", "Use of Scaffold Supports", and two of the relational analyses—"Who's read whose notes?" and "Who's built on whom?"

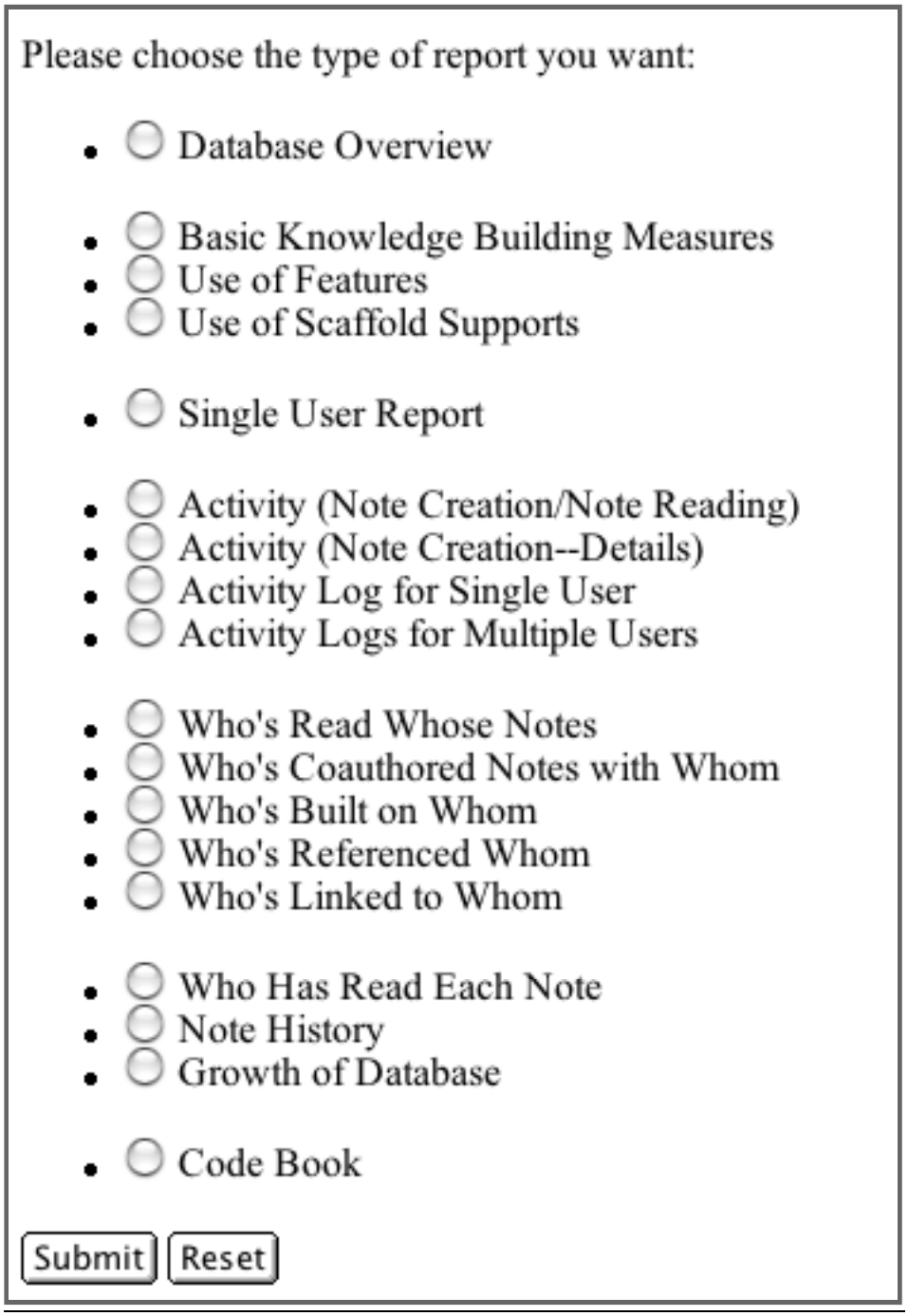

Figure 1. Analytic Toolkit Menu Showing 17 Types of Analysis

The basic knowledge building measures are as follows. 1) The number of notes created; 2) the percentage of notes with links to other notes; 3) the percentage of notes

that have keywords; 4) and the percentage of notes in the database that a student has read. Generally, it is desirable to have high values for all these measures. Previous studies suggest that the amount of writing is correlated with depth of explanation (van Aalst, 1999). A database with a large number of linked notes may indicate a high degree of knowledge integration. Students new to KF initially may write notes that are represented as unconnected icons. If they write responses to notes that way the ideas may be connected but this is not apparent graphically from the view. Using the "build-on" feature to make a response, the link is made more explicit and the view begins to look like a network of ideas that reflects the epistemology of knowledge building (e.g. idea diversity, see Scardamalia, 2002). At a higher level of sophistication, students can drop one note into another note, creating another type of link. This feature is used to write notes that respond to several notes at once, and represents a stronger form of knowledge integration. Keywords (and scaffolds) are designed to make the database more searchable, and hence make notes more visible. A high degree of collaboration requires that it is easy to find relevant ideas in the database—there have to be multiple paths to notes. The number of notes read is also a strong predictor of depth of explanation, at least for students in elementary school (e.g. van Aalst, 1999). To these basic measures from the ATK we add the overall use of scaffold (supports). Scaffolds are very important because they can assist the writer and reader in maintaining focus on "theory building." For example, when a student starts an idea with "My theory" we know that we are dealing a conceptual artifact that is to be examined, debated and improved by the community. When a student begins a note with "New information" we don't interpret the note that way. Information can be used to defend or question an intellectual artifact—but it is not itself an

intellectual artifact. With scaffolds, a student can, when entering the database, search for new theories or new information and therefore contribute in a way focused on theory building. In an exploratory study, van Aalst and Chan (2001) found that the use of scaffolds correlated with qualitative portfolio evaluations.

Although the above measures are based on individual students, they collectively do have a social dimension. We suggest that in a collaborative culture—a culture in which students are committed to collaborative effort—students are individually making efforts to contribute ideas, integrate knowledge, and make the database as useful as possible as a resource for knowledge building by adding keywords, scaffolds, etc. Thus, these variables may collectively provide a preliminary probe into a key feature of knowledge building. In this paper, we combine the percentage of notes that are linked, the percentage of notes with keywords, and the number of scaffold uses per note into an average z-score that we will call KF features, reflecting how students are individually using the basic features of KF designed to support knowledge building.

From the various techniques available from SNA, we focus on some very general features of networks. Consider the network shown in figure 2, showing how a hypothetical group of five students interact by building on each other's notes. In the network students are represented by the nodes S1, S2, …, S5, and directed links indicate that one student has built onto notes by another student. So, S2 has built onto two notes by S1, and S1 has built onto four notes by S2.

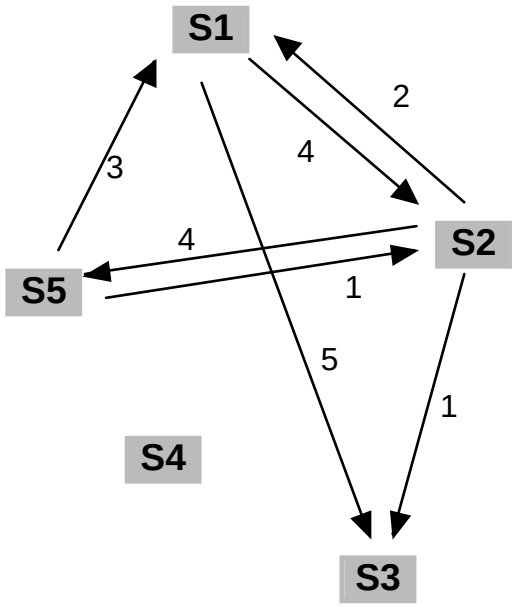

Figure 2. A Network of Students Interacting by Building on Each Other's Notes

In this network, we see that S4 is not involved in building-on. Although the other students may have read notes by S4 and may even have responded to some of them, the possible connection to ideas contributed by S4 is not explicit in the sociogram. S3 may be an important student in the network in that two students built onto ideas by S3. This may reflect a division of labor in the network. Note that S5 does not build on S3 directly, S5 builds onto S2, and S2 builds onto S5. So, S2 may act as an intermediary that communicates ideas by S5 to S3.

To obtain a simple description of the network, we can use three network variables as follows:

Indegree. This is the total number of notes of a given student that are built-on by others. A high indegree for a specific student indicates that the student's ideas may be influential in the discourse. A high average indegree for the network indicates that there

is a high degree of building on each other's notes, one hallmark of collaborative effort. If there is a large variance in indegree, this may indicate a division of labor in the network, but it may also indicate social inequity. Some students may be very powerful because their ideas are taken seriously, while the ideas of others are ignored. Of course, students may be building onto notes by a specific student because that student writes better notes than other students in the network.

Outdegree. This is the total number of notes by other students that a specific student builds on. Observe that the average of outdegree over the network is equal to the average indegree. A large variance in the outdegree over the network may reflect different levels of commitment to collaborative effort, but it may also reflect individual differences in the qualities of the rest of the network. A given student may have a low opinion of notes written by others in the network and may not feel a compelling reason to build on notes by others; another student may have a different opinion.

Betweenness. This is determined by the extent to which a student is a "broker" if information flow. If information flow among students is often indirect and via a given student, that student has a high betweenness. If a network has a high average betweenness, it suggests that there are at least a few information brokers. Such brokers hold powerful positions in the network, so this is undesirable. The network would support a more democratic form of knowledge building when there are many direct links between students, rather than individual links. The democratization of knowledge is an important feature promoted by the knowledge building perspective (Scardamalia, 2002).

Although the interpretation of indegree, outdegree, and betweenness for a network requires additional, qualitative, knowledge of the social structure of the class, we posit

that they can be used as descriptive measures of collaborative effort that reflect how the community is working as a whole, rather than how individual students are using KF features. In a knowledge building community in which there is equitable participation, and everyone has opportunities to develop discursive practices, we would expect high averages for indegree and outdegree, with low standard deviations; we would also expect a low average betweenness. In table 1 we show indegree, outdegree, and betweenness for the network in figure 2.

Table 1. Indegree, Outdegree, and Betweenness for the Sociogram of Figure 1

Student	Indegree	Outdegree	Betweenness
S1	5	9	4.2
S2	5	7	12.5
S3	6	0	0
S4	0	0	0
S5	4	4	0
M	4.0	4.0	3.7
SD	2.1	3.6	5.4

We next present two case studies in which we used ATK and SNA measures to develop a manageable description of collaborative effort in two different databases. The goal is not to evaluate and compare the discursive practices in the two classes, but to illustrate how we can learn about the discursive practices from analyses such as we conduct. The specific research goals are as follows: (a) To examine the patterns of student engagement and collaboration on KF using Analytic Toolkit; (b) To examine patterns of social interactions and collaboration using SNA; and (c) To investigate collaborative aspects of knowledge building as related to changes over time, gender differences, and relations between knowledge building indices and social interactions.

CASE STUDY 1

Method

Participants

The participants were 28 grade four students (approximately ten years old) in a school in metropolitan Vancouver, one of the most multicultural regions in Canada. The teacher was in his third year of teaching, had attended a Summer Institute on using KF and was in his first year of using KF and the knowledge building perspective in his teaching. He was assisted by a research assistant who was a participant observer in his class two to three times a week (see also Hill, van Aalst, & Cummings, 2003, this symposium). The research assistant had two years of experience working with Knowledge Forum, and had a thorough understanding of the knowledge building perspective from a graduate course on the subject. The study was conducted within the first few months after the children were introduced to KF.

Classroom procedures

Between January and June, the class completed two units specifically utilizing a knowledge building philosophy; one on electricity and the other on First Nations studies. However, the teacher had worked with the students to establish a sense of community in the classroom since the beginning of the school year. In January, the class engaged in several discussions regarding the nature of knowledge, as well as the knowledge construction process. Four computers were set up in the classroom for students to access Knowledge Forum, but the students mainly accessed Knowledge Forum during their

regular visits (two to three times per week) to the computer laboratory, which housed approximately thirty iMac computers. The teacher often coordinated classroom activities with activities related to Knowledge Forum. For example, the teacher might conduct an experiment in the classroom and then encourage students to write about the experience on Knowledge Forum. Alternatively, the teacher might ask the students to prepare for a class discussion by reading notes in the Knowledge Forum database.

Measures and analysis

The following variables were obtained from the ATK: 1) The number of notes created; 2) the percentage of notes with links to other notes; 3) the percentage of notes that have keywords; 4) the percentage of notes in the database that a student has read; and 5) the number of scaffold supports used per note. These variables were combined into a KF Features score in order to calculate correlations between a general score that reflects how individuals use the software features and other variables in the study. The KF features scores were calculated as the average of the z-scores of the five above-mentioned ATK scores. A large KF features scores indicates, roughly, that a student is writing a relatively large number of notes that use the KF features designed to make notes more visible in the database; to a lesser extent, it reflects that a student is reading a large percentage of the notes examined.

We also analyzed the following relational data from the ATK with SNA techniques: who has read whose notes, and who has built on whose notes. The analyses focus on the indegree, outdegree, and betweenness of the networks for both of these types of data. To see if there were changes over time in both the basic knowledge building

indicators and the relational data, the database was divided into two phases of equal duration: Phase 1 (January 2 to March 5), and Phase 2 (March 6 to May 5).

Results

First, we present basic statistical measures of several aspects of working with Knowledge Forum to provide a basic sense of the students' performance in participating in online knowledge building discourse. Following this, the SNA results are presented.

Basic knowledge building indicators from the ATK

Because the data set is small, we present the data for individual students in table 2, as well as the averages and standard deviations. As the table shows there were only marginal differences in these basic knowledge building indicators between the two phases. Only the percentage of notes read went up significantly, from 26.9% to 40.3% (Wilcoxon, $Z=2.16$, $p<.05$). That brought the amount of reading up to what we usually suggest students should be doing to have a reasonable level of awareness of other students' notes. Some of the other indicators remained lower than expected, however. In particular, the percentage of notes that were linked to other notes (below 30% in both phases) was much lower than the 60% to 80% typically found. This confirms the teacher's impression that students were primarily writing isolated notes rather than trying to build on and integrate each other's ideas. This effect may be an artifact of the students' experience with KF, but the ATK data provide a diagnosis that there is something to work on in a simple manner. Note that although the number of scaffold uses was relatively high (on average more than one per note), this was due to a small number of students; nearly half of the students did not use them at all.

Table 2. Use of Knowledge Forum Features for Phase 1 (January 1 - March 5) and Phase 2 (March 6 - May 5)

Student	Notes Created		% Notes Linked		% Notes with Keywords		% Notes Read		Scaffold Uses per Note	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
S1	5	13	40%	46%	0%	0%	12%	16%	0	0
S2	5	4	20%	50%	0%	25%	49%	48%	1	1
S3	13	13	38%	23%	0%	0%	11%	6%	3	5
S4	18	1	61%	0%	6%	100%	35%	3%	6	1
S5	15	13	13%	8%	53%	31%	17%	45%	2	9
S6	24	13	17%	23%	0%	0%	29%	44%	2	0
S7	8	6	13%	0%	0%	0%	30%	21%	3	0
S8	6	16	0%	56%	17%	63%	8%	30%	0	0
S9	15	4	53%	25%	33%	0%	21%	24%	0	0
S10	5	7	0%	14%	0%	0%	29%	17%	8	0
S11	10	9	0%	33%	0%	0%	25%	22%	0	3
S12	22	20	55%	5%	9%	0%	61%	96%	0	3
S13	36	10	81%	30%	6%	0%	50%	47%	1	0
S14	13	6	69%	17%	23%	17%	18%	6%	3	0
S15	4	4	0%	25%	25%	25%	5%	55%	0	0
S16	6	17	17%	24%	17%	24%	30%	71%	0	2
S17	5	21	0%	43%	20%	71%	2%	29%	0	0
S18	10	8	50%	75%	10%	0%	17%	44%	2	0
S19	10	5	10%	20%	10%	0%	41%	67%	6	0
S20	11	8	36%	25%	18%	25%	17%	99%	0	1
S21	11	14	0%	14%	36%	21%	90%	85%	1	0
S22	5	11	40%	36%	0%	9%	24%	56%	0	0
S23	6	13	33%	31%	0%	15%	19%	25%	2	0
S24	7	7	0%	29%	0%	0%	6%	10%	0	0
MEAN	11.3	10.1	26.9%	27.2%	11.8%	17.8%	26.9%	40.3%	1.7	1.0
SD	7.6	5.3	25.1%	17.8%	14.2%	26.3%	20.1%	28.0%	2.2	2.1

There were some noteworthy changes for individual students. For example, in phase 1, S13 wrote the largest number of notes (36), whereas in phase 2, the same student

wrote only 10 notes, near the class average in that period. Taking the notes created as an example, we can identify three patterns of change. For some students (S1, S8, S16, S17, S22, and S23) the number of notes created increased substantially (doubled); other students remained consistent (S2, S3, S11, S12 S18, S21, and S24); and for yet other students the number of notes created decreased (S4, S6, S9, S13, S14, S19). As a result, the overall statistic (the average number of notes created) did not change significantly, but who was contributing did. The findings were similar for the other variables; none of the five variables correlated across the two phases.

Social positions and interactions from SNA

In table 3 we show the means and standard deviations for the indegree, outdegree, and betweenness for phase 1 and phase 2, for reading as well as build-on notes. As explained earlier, the average indegree and outdegree for the network are equal except for computational error, but the standard deviations generally vary. The indegree and outdegree for building-on tend to be much smaller than for reading as students build onto only a fraction of the notes that they read. For example, the ratio of the average indgree for building-on to the indegree for reading was only .03 for phase 1. However, there was considerable variation in the extent to which students were building onto notes, reflected by large standard deviations. In phase 1, building-on had a large betweenness and standard deviation, suggesting that there were a small numbers of information brokers, who mediated the flow of information. In phase 2 this effect had diminished.

Table 3. Mean (SD) of Indegree, Outdegree, and Betweenness for Phase 1 (January 2-March 5) and Phase 2 (March 6-May 5)

	Indegree		Outdegree		Betweenness	
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Reading	116 (62)	97 (46)	116 (77)	97 (67)	.49 (.23)	.79 (.58)
Building-on	3.7 (3.3)	1.3 (1.8)	3.6 (6.7)	1.3 (2.1)	5.1 (6.51)	.06 (.16)

Gender effects on SNA measures

Table 4 shows means and standard deviations for the network variables, for phase 1 and phase 2. MANOVAs showed that in both phases girls read notes by other students more than boys did. For example, in phase 1 the outdegree for girls was 155 (SD=79), compared with 62 (SD=27), $F(1, 22)=12.70$, $p<.005$, partial eta-squared=.37.

Table 4. Male and Female Participation in Study 1, Phase 1(January 2 – March 5) and Phase 2 (March 6 – May 5)

	Phase 1		Phase 2	
	Male	Female	Male	Female
Indegree Reading	111 (50)	120 (35)	100 (35)	94 (54)
Outdegree Reading	62 (27)	155 (79)	39 (19)	138 (58)
Betweeness Reading	.44 (.24)	.52 (.22)	.58 (.45)	.95 (.63)
Indegree Building on	3.30 (2.83)	4.00 (3.62)	1.30 (1.83)	1.36 (1.82)
Outdegree Building on	1.90 (2.50)	4.79 (8.38)	1.20 (2.49)	1.43 (1.95)
Betweeness Building on	6.13 (9.1)	4.38 (4.02)	0.00 (0.00)	0.10 (0.20)

A repeated measures design showed that there also was a general, gender-independent, general decline of interactivity over time represented by these variables, F(1,23), 6.27, p<.05, partial eta-squared=.21. The last effect is difficult to interpret for us, but we suggest that this information would be useful to the teacher—effort could be renewed to enhance interactivity through reading and building on notes widely.

Relationships between ATK and SNA variables

In table 5, we show (Spearman) correlation coefficients between all the variables: indegree, outdegree, betweenness, and the KF features score. The upper number in each cell is the coefficient for phase 1 (January 2 – March 5) and the lower number the coefficient for phase 2 (March 6 – May 5).

Table 5. Spearman Correlation Coefficients, Study 1

	Indegree Reading	Outdegree Reading	Betweenness Reading	Indegree Build-on	Outdegree Build-on	Between-ness Build-on
Indegree Reading	--					
Outdegree Reading	-.08 -.10	--				
Betweenness Reading	.09 .34	.63** .44*	--			
Indegree Build-on	.46* .64**	.13 .11	.06 .28	--		
Outdegree Build-on	.66** .23	.04 .12	.10 .02	.42* .19	--	
Betweenness Build-on	.58** .12	.08 .38	.05 .31	.64** .28	.86** .24	--
KF features	.54** .32**	.06 .00	.12 -.22	.48** -.20	.66** .52**	.59** .-.04

Notes. * p<.05; ** p<.01.
KF Features is the average of the z-scores of the percentage of notes with links, the percentage of notes with keywords, and the number of scaffold uses per note.

The following observations can be made form table 5.

- In both phases KF features was strongly correlated with indegree for reading and outdegree for build-on. Since KF features does not include the number of notes created or read directly, this means that students who added links, keywords, and scaffolds had more notes that were read by other students; they also built on notes more than other students.
- In phase 1, there was a strong correlation between KF features and betweenness for build-on. From table 3 we know that there were some brokers of information in phase 1, but not in phase 2; now we also know that these brokers tended to use links, keywords, and scaffolds more than other students.
- The correlations between KF features and the network variables generally declined over time (in some cases they even changed sign). As table 2 showed, the most active participants were not the same students in phase 1 and phase 2. From table 5 we see that in phase 2 it was no longer true that adding features to notes—links, keywords, and scaffolds—would tend to improve the chance that the student's notes would be built on.
- There was essentially no relationship between indegree and outdegree for reading, for both phases. This means: <u>If a student read many notes written by other students, it was not usually the case that the student's notes were also read widely.</u>

- Indegree for building-on was strongly correlated with indegree for reading but not with outdegree for reading; but indegree for build-on was correlated with outdegree for build-on. This suggests a simple mechanism: Students read notes and then build onto some of those notes. Reading many notes by other students generally did not improve the chance that a student's notes would be built-on by other students, but additionally building on note by other students did.

Discussion

The analysis of basic knowledge building measures showed that the number of notes written, the percentage of notes with links, the percentage of notes with keywords, and the percentage of notes read all were low, although the last improved with time. Further, these measures did not correlate between the two phases, and a substantial number of students who participated at a high level in phase 1 did not continue to do so in phase 2. The SNA data showed that there was no correlation between indegree and outdegree for reading, suggesting that reading widely in the database did not necessarily mean that a student's notes would be read more widely as well. There was a simple mechanism at work: Students read notes and then built onto some of those notes. But if a student read and built onto notes by other students, this activity was not usually reciprocated. And one gender effect was found: girls read the notes of other students more widely than boys did (the difference did not extend to building onto notes).

Most of the results suggest that what van Aalst and Chan (submitted) call the pedagogical knowledge building principle collaborative effort and what Linn and Hsi

(2000) call knowledge integration was underdeveloped in this class's database. There was less effort to make notes visible—i.e. make the database searchable—by adding keywords and scaffolds to notes than in other databases by elementary school children that have sustained progressive inquiry. For example, Messina, Reeve, and Scardamalia (2003) report that a grade four class put keywords on more than 50% of notes and had also read more than 50% of all notes, although the percentage of notes that were linked was still relatively low at 34%. There also was a lack of reciprocity in reading and building on other students' notes, suggesting that even if students were reading and building onto the notes of others, their own ideas might remain obscure. The results also suggest that things got worse as time went on. In phase 2 other students were the most active ones than in phase 1, and this was accompanied by a loss of interaction and weaker relationships between interaction and use of the KF features.

These results are best interpreted by the teacher and students in relation to their own history, available resources, and culture. The class was quite successful in posting questions and theories, using text and graphics, and the quality of these is not revealed by analysis of this type. Very likely, some of those theories were discussed in face-to-face mode, where they were built on by more students, leaving no reason to come to the database to discuss them further. Or perhaps there were reasons to do so but no opportunity to visit the computer lab. At the same time, we suggest, there is value in promoting collaborative effort and knowledge integration; Chan, van Aalst, and Lee (2002), for example, found a positive relation between collaborative effort and conceptual change.

Whether the teacher and students will see a problem to improve upon will also depend on what other problems there may be at this particular time in the class's history and classroom life. But analyses such as this study will provide the class and teacher with empirical evidence to consider in its goal-setting.

CASE STUDY 2

Method

Participants

The participants were 26 students in a grade nine class preparing for an International Baccalaureate (IB) program at a high school in metropolitan Vancouver; the students were taking a general course on research and personal development (career preparation). The teacher was a mathematics teacher with 10 years of experience; he was in his second year of teaching with KF. A few of the students had also used KF with this teacher at their previous (middle) school.

Classroom procedures

In the first semester, the class spent some time developing work habits appropriate to the IB program and conducted a number of assignments, including an individual project on environmental studies. The class had also examined various sides of responsibility, as it applies to drinking and driving. At the end of the semester this became a current topic in British Columbia, as the province's premier was arrested for driving under the influence of alcohol—just as the students were beginning their work on KF. The teacher chose this as a problem for discussion because the class had studied it

earlier in the semester. The students had several projects underway in the few weeks that they discussed this topic, and the teacher had access to a computer lab whenever he needed it during this class. Consequently, the students could go onto KF several times a week to contribute to the database; they also accessed it from their home computers.

Measures and analysis

In this study, the whole discussion took place within a few weeks at the end of the semester, so it was not useful to divide the work into two phases. We again retrieved the following measures from the KF server software: Notes Created, Percentage of Notes with Links, Percentage of Notes with Keywords, Percentage of Notes Read, and the Scaffold Uses, for the month of January, 2003. We constructed the KF Features score from the average of the z-scores of the various basic knowledge building measures. We also retrieved relational data—who has read whose notes and who has built on whose notes—and calculated the indegree, outdegree, and betweenness for both of these data sets. We again examined gender differences in participation levels.

Results

Basic statistical results from the ATK

The summary data are shown in table 6. The table shows that this was a period of intense activity on KF, with an average number of notes of 16.7; the percentage of notes linked and the percentage of notes with keywords were also high, 83.6% and 79.6% respectively. The percentage of notes read, by contrast was relatively low, 21.6%. The table also shows that there was little variation in the extent to which notes were linked and had keywords, and more variation in the number of notes written, read, and the

number of scaffold uses per note. A few students wrote a small number of notes (S7, S16, and S22), but even these students wrote at least a few notes per week. Note that the percentage of notes with links and the percentage of notes with keywords in table 6 are very high compared with those in study 1, reported in table 2.

Table 6. Use of Basic Knowledge Forum Features, Study 2

Student	Notes	% Notes Linked	% Notes with Keywords	%Notes Read	Scaffold Uses per note
S1	11	100%	91%	20%	.64
S2	15	93%	93%	8%	.93
S3	23	74%	91%	44%	.91
S4	15	80%	53%	29%	.07
S5	17	76%	94%	11%	.18
S6	21	95%	76%	29%	.05
S7	5	60%	40%	12%	.60
S8	31	90%	68%	32%	.10
S9	13	92%	62%	22%	.92
S10	8	63%	63%	11%	.88
S11	10	90%	100%	13%	.90
S12	32	97%	78%	44%	.25
S13	11	91%	91%	27%	1.00
S14	30	97%	83%	33%	.90
S15	33	88%	91%	30%	1.00
S16	9	78%	56%	7%	.33
S17	11	91%	82%	21%	.82
S18	20	95%	90%	20%	.70
S19	20	75%	60%	37%	.55
S20	25	92%	72%	36%	1.04
S21	20	90%	80%	31%	.20
S22	7	71%	71%	12%	.86
S23	10	90%	70%	9%	.10
S24	14	71%	64%	11%	.79
S25	13	85%	100%	7%	.77
S26	10	40%	80%	5%	.20
Mean	16.7	83.2%	76.9%	21.6%	.60
SD	8.2	14.0%	15.6%	12.1%	.35

Social interaction findings from SNA

In table 7 we show the means and standard deviations for the indegree, outdegree, and betweenness, for reading and building on notes.

Table 7. Mean (SD) of Indegree, Outdegree, and Betweenness

	Indegree	Outdegree	Betweenness
Reading	71 (42)	72 (46)	1.2 (.9)
Building-on	8.4 (6.9)	8.4 (6.3)	4.3 (4.8)

Again, for indegree and outdegree the averages over the network are equal except for computational error; the standard deviations are similar to each other as well. The ratio of building-on to reading for degree was .12, somewhat more favorable than the .03 in study 1. Observe that building-on has a high betweenness, with a large standard deviation. This means that there were a few brokers, who mediated the flow of information. S8, S12, S14, and S15 are possible candidates.

Gender Effects on SNA measures

Table 8 shows the averages and standard deviations of the network variables, differentiated by gender. A MANOVA did not reveal a gender main effect; nevertheless, girls built onto notes by other students than boys did, $t(23)=2.4$, $p<.05$. On average girls built onto 11.3 notes by other students (SD=6.7) and boys built onto 5.8 notes (SD=4.8).

Table 8. Mean (SD) Male and Female Participation in Study 2

Measure	Male	Female
Indegree Reading	72 (46)	71 (41)
Outdegree Reading	66 (55)	79 (34)
Betweeness Reading	1.2 (1.1)	1.1 (.8)
Indegree Building-on	6.6 (3.7)	10.4 (8.9)
Outdegree Building-on	5.8 (4.8)	11.3 (6.7)
Betweeness Build-on	4.9 (5.2)	3.7 (4.6)

Relationship between SNA and ATK variables

In table 9, we show (Spearman) correlation coefficients between all the variables: indegree, outdegree, betweenness, and the KF features score.

Table 9. Spearman Correlation Coefficients for Study 2

	Indegree Reading	Outdegree Reading	Betweenness Reading	Indegree Build-on	Outdegree Build-on	Betweenness Build-on
Indegree Reading	--					
Outdegree Reading	.54**	--				
Betweenness Reading	.81**	.80**	--			
Indegree Building-on	.73**	.58**	.66**	--		
Outdegree Building-on	.40	.46*	.33	.60**	--	
Betweenness Building-on	.71**	.53**	.73**	.61**	.12	--
KF features	.23	.02	.12	.24	.18	.00

Notes. * $p<.05$; ** $p<.01$.

The following observations can be made from table 9.

- There were no statistically significant correlations between KF features and the network variables. This is different from the strong relationships in phase 1 of study 1, but can be explained as follows. In this study, there was very little variation in two variables that make up the KF features measure—the percentage of notes with links and the percentage of notes with keywords; for each variable the standard deviation was less than approximately 20% of the mean.
- There was a strong relationship between indegree and outdegree for reading, $r=.54$, $p<.01$. This suggests that students who read many notes by other students also had many of their notes read by other students.
- As expected, there was a strong relationship between indegree for reading and for building-on. This, again, is the simple mechanism of reading notes and then building onto them. But in addition, there were strong relationships between indegree for building-on and outdegree for reading and outdegree for building-on, rs .58 and .60, ps<.01. This is a stronger relationship than in study 1, where receiving build-on notes was not significantly related to reading the notes of other students.

Discussion

There was much excitement when the students were discussing drinking and driving and related topics. The students wrote 435 notes, about half of which were written within a few days. Although the students had no experience with KF and little instruction on its features, most of the basic knowledge building measures from the ATK were high

during this one-month period—with the exception of the percentage of the percentage of notes read (M=21.6%, SD=12.1%). In contrast with study 1, there was a high degree of reciprocity in that reading and building onto the notes of other students was accompanied by having one's own notes read and built on. There was a small gender effect: Girls built onto notes by other students more than boys did. But this effect was weaker than in study 1 (it did not lead to an overall gender effect for al the network variables).

The data suggest a higher degree of collaborative effort and knowledge integration than study 1 did. There appeared to be a tendency to read and build on the notes of other students, and that appeared to be reciprocated. The ATK data compare favorably with other examples of progressive discourse by high school students (Chan, van Aalst, & Lee, 2002).

Clearly, these data do not necessarily show that knowledge building was going on. We did not evaluate the quality of the note content to see if knowledge advanced were made. Nevertheless, we suggest that the ATK and SNA show that a level of interaction was present that we have observed as important to a progressive discourse. Still, in this database there was room for improvement. It would probably desirable to have more reading and efforts could be made to eradicate the gender difference.

DISCUSSION AND CONCLUSIONS

The goal of this paper was to explore the assessment of individual and social aspects of knowledge building. Despite a widespread emphasis on social constructivism in the design of educational experiences, assessment still tends to focus on individual, final knowledge (Chan & van Aalst, in press). If the process by which people construct

knowledge is to be valued, it must be represented in how we approach assessment. In addition, although knowledge advances often arise from a class's discourse without being planned or even anticipated, we can heuristically determine what aspects of the learning environment may have supported progress toward new knowledge and attempt to improve the learning environment. Thus, we need to see to what extent the discourse has the features of knowledge building discourse, using analysis on knowledge building concepts. Our use of pedagogical knowledge building principles to scaffold and assess knowledge building with portfolios is one example of doing this (van Aalst & Chan, under review; Chan, van Aalst, & Lee, 2002). In this paper, we began to extend our framework for assessment by exploring how information from server logs can be used to inform continual improvement of knowledge building discourse. Such data are "naturalistic": They are produced by the students' normal work and do not require an intervention. We focused specifically on collaborative effort.

In a collaborative culture, students work together to solve problems. In the case of knowledge building, the objective of the students' work is the advancement of communal and personal knowledge, and the pedagogical knowledge building principle of collaborative effort refers to the extent to which students are committed to helping each other to meet this objective. By assessing collaborative effort, we are assessing an aspect of knowledge building that is social at a conceptual level. As explained earlier in the paper, we suggest to assess collaborative effort by looking at how individual students are using features of Knowledge Forum such as note links, keywords, and scaffolds. These features are designed specifically to support knowledge integration and to make notes as

visible in the database as possible. If Knowledge Forum is used as a tool to support a collaborative culture we would expect individual students to use these features.

With the SNA measures we additionally probed collaborative effort at a more systemic level. To see this, again consider the simple network in figure 1, which we used earlier to explain indegree, outdegree, and betweenness. In this network of five nodes, twenty directed links are possible, of which only seven of these were realized in the network shown. A network with more links would have had more pathways for communication; as a result, it would be expected to be a stronger support for knowledge integration and collaboration. The fact that one node (S5) was not connected to the other nodes at all meant that the indegree and outdegree of the other nodes was artificially low. Further, if there had been a link to and from S5 so that information flow via S5 was possible, the status of S2 as the primary broker would have been reduced. So these variables, although measured at the individual level, provide information of the network as a whole. In a highly interactive network, we would expect high averages for indegree and outdegree, and low averages for betweenness; if the extent of interaction (i.e., the numbers along the arrows) is additionally distributed evenly over the connected nodes, then the standard deviations are also low. Although the social structure of knowledge building communities has been assessed with SNA before (e.g. Hakkarainen & Palonen, 1999), we connected the findings to the individual use of the features of Knowledge Forum.

The two case studies explored the combination of ATK and SNA in two very different contexts. In study 1, we had a class of grade 4 students in which interactivity in KF was known to be low (Hill, Cummings, & van Aalst, 2003, this symposium). Our

analysis provides a prototype of an artifact that could be used by the teacher to attempt to improve this. It gives the teacher more than a hunch to start from, but also something for assessing the success of attempts to improve. The first level at which the lack of interactivity was evident was in the basic knowledge building measures. However, when presented with such data, students tend to increase how much they are contributing to the database, but not how they are contributing—they simply try to improve the ATK scores! The SNA data provided additional insight into what was going on. An important finding was the lack of reciprocity. We suggest that from a motivational perspective it is important to have a high degree of reciprocity. A student is not likely to continue to read notes by other students and create links if other students in the class are not committed to doing the same with the student's notes. In phase 1 of the study we found relationships between using the features of KF and the extent to which notes were read and built-on. Information of this kind could explicate reasons for using these features for students. Finally, the analysis showed a general deterioration of interactivity over time. This, too, would be valuable information for the teacher. The second case study involved a class of academically strong and motivated students—it was a grade 9 class preparing for the International Baccalaureate Program. We knew that the students were very excited about the discussion they were having in KF, and it was a more positive experience than we had observed in other classes at the same grade level. The analysis provided a way to document that excitement. It was reflected by high averages on most of the basic knowledge building measures, and generally more reciprocity in the interactions. Nevertheless, there was information in the data that the class could use to improve the discourse. Examples were the relative low use of scaffolds, the presence of a few brokers

of information, and a gender effect for building-on. In this study, there were no significant correlations between the SNA variables and use of the KF features.

It can probably not be overemphasized that only the teacher and students can interpret the results of analyses such as we have provided in terms of classroom life. What may be a problem for one class may not be interpreted the same way by another class. There are no standards for the number of notes students should read or write, for adding scaffolds, and so on. In a class that makes effective use of the search features of KF it may be adequate to read only 15% of the notes, but a class who does not use these tools will need to do more reading. However, the knowledge building perspective does offer a standard—the standard of continual improvement. The class needs to ask continually if it is creating new community knowledge and if that knowledge is the result of an equitable and democratic process (Scardamalia, 2002). For example, did most students have voice in articulating problems of understanding or in sorting out what has been learned? Whatever things might be improved, the learning goals and goals for improvement are constituted by the community and depend on its resources, interest, and history. In a sociocultural perspective problems are social constructions, and what one class sees as problematic another may not. Nevertheless, we argue, analyses such as we have reported here can provide information that the teacher and students can base their decisions on.

The case studies provide only prototypes of analyses, and much more work is needed to develop tools and classroom practices based on them. The ATK has been used before by teachers to guide continual improvement of knowledge building (Chan, van Aalst, & Lee, 2002; Messina, Reeve, & Scardamalia, 2003; van Aalst & Chan, under

review). We suggest that the ATK data should be processed further with SNA techniques to make the social structure of the knowledge building discourse more explicit; software is required to put this in the hands of teachers and students as well. Concepts such as "indegree" and "outdegree" may not be useful directly to students, but notions such as the extent to which there are pathways for communication in a community or the extent to which there are powerful brokers may be more promising. Improving connectivity in a community, we think, would provide a better support to knowledge building than improving individual ATK measures such as we have used in these studies and would mirror the connectivity between ideas that knowledge building discourse reflects. Additional work is also needed—before software design, we suggest—to elaborate a fuller framework of measures to assess knowledge building. That is, research is needed to examine more fully the relationships between the ATK and SNA variables and other measures that reflect knowledge building. That would take us beyond collaborative effort to progressive problem solving and the intended outcome of knowledge building discourse, new communal knowledge.

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REFERENCES

Bereiter, C. (2002) Education and mind in the knowledge age. Mahwah, NJ: Lawrence Erlbaum Associates.

Bereiter, C., & Scardamalia, M. (1996) Rethinking learning. In D.R. Olson, & N. Torrance (Eds.), The handbook of education and human development: New models of learning, teaching and schooling (pp. 485-513). Cambridge, MA: Basil Blackwell.

Bielaczyc, C., & Collins, A. (1999) Learning communities in classrooms: A reconceptualization of educational practice. In C. M. Reigeluth (Ed.), Instructional design theories and models, Vol II (pp. 269-292). Mahwah, NJ: Lawrence Erlbaum Associates.

Borgatti, S. P., & Everett, M. G. (1992). The notion of position in social network analysis. In Marsden, P. (Ed.), Sociological Methodology, 1992, London: Basil Blackwell.

Brown, J.S., Collins, A., & Duguid, A. (1989). Situated cognition and the culture of learning. Educational Researcher, 18 (1), 32-42.

Burtis, J. (1998) The analytic toolkit. The Ontario Institute for Studies in Education, The University of Toronto: Knowledge Building Research Team.

Carley, K.M. (1986a). Knowledge acquisition as a social phenomenon. Instructional Science, 14, 381-438.

Carley, K.M. (1986b). An approach for relating social structure to cognitive structure. Journal of Mathematical Sociology, 12, 137-189.

Chan, C., & van Aalst, J. (2003, April). Self-reported beliefs and attitudes about learning and collaborative knowledge building. In J. van Aalst and C. Chan (Chairs),

Probing individual, social, and cultural aspects of knowledge building, a structured poster session presented at the annual meeting of the American Educational Research Association, Chicago, IL, April 21-25, 2003.

Chan, C., & van Aalst, J. (in press). Learning, assessment, and collaboration. In J.-W. Strijbos, P.A. Kirschner, and R. Martens (Eds.), What we know about CSCL in higher education. Dordrecht, the Netherlands: Kluwer.

Chan, C., van Aalst, J., and Lee, E. (2002) Assessing and fostering knowledge building among Chinese students in a Hong Kong classroom. Paper presented at the Annual meeting of the American Educational Research Association, New Orleans, LA.

Cho, H., Stefanone, M. & Gay, G. (2002). Social network analysis of information sharing networks in a CSCL community. In Proceedings of the Computer-Support for Collaborative Learning (CSCL) 2002 Conference, G. Stahl (Eds.), Jan. 7-11, Boulder Colorado, NJ: Lawrence Erlbaum Associates, 43-50.

Everett, M. G. & Borgatti, S. P. (1999). The centrality of groups and classes. Journal of Mathematical Sociology, 23(3), pp181-201.

Hakkarainen, K. & Palonen, T. (1999). Analyzing patterns of interaction in a computer-supported classroom. A paper presented at the International Sunbelt Social Network Conference, April 13-15, 1999, Vancouver, Canada.

Hakkarainen, K. (1998). Epistemology of scientific inquiry and computer-supported collaborative learning. Unpublished doctoral dissertation, University of Toronto, Toronto, Ontario, Canada.

Hakkarainen, K., Lipponen, L., Järvelä, S., & Niemivirta, M. (1999). The interaction of motivational orientation and knowledge-seeking inquiry in computer-

supported collaborative learning. Journal of Educational Computing Research, 21, 263-281.

Haythornthwaite, C. (1996). Social network analysis: An approach and technique for the study of information exchange. Library and Information Science Research. V18(4), p323-42.

Hewitt, J. (1996). Progress toward a knowledge building community. Unpublsihed doctoral dissertation, University of Toronto, Toronto, Canada.

Hogan, K. (1999). Socialcognitive roles in science group discourse. International Journal of Science Education, 21 (8), 855-882.

Laat, M. (2002). Network and content analysis in an online community discourse. In Proceedings of the Computer-Support for Collaborative Learning (CSCL) 2002 Conference, G. Stahl (Eds.), Jan. 7-11, Boulder Colorado, NJ: Lawrence Erlbaum Associates, 625-626.

Lave, J., & Wenger, E. (1991) Situated learning: Legitimate peripheral participation. Cambridge University Press. Cambridge, England.

Lipponen, L., Rahikainen, M., Lallimo, J., & Hakkarainen, K. (2001). Analyzing patterns of participation and discourse in elementary students' online science discussion. In P. Dillenbourg, A. Eurelings., & K. Hakkarainen (Eds.), European Perspectives on Computer-Supported Collaborative Learning. Proceedings of the First European Conference on CSCL (pp. 421-428). McLuhan Institute: University of Maastricht. Available: http://www.mmi.unimaas.nl/euro-cscl/Papers/102.doc

Martinez, A., Dimitriadis, Y., Rubia, B., Gomez, E., Garrachon, I. & Marcos, J. A. (2002). In Proceedings of the Computer-Support for Collaborative Learning (CSCL)

2002 Conference, G. Stahl (Eds.), Jan. 7-11, Boulder Colorado, NJ: Lawrence Erlbaum Associates, 631-632.

Oshima, J., Scardamalia, M, and Bereiter, C. (1996) Collaborative learning processes associated with high and low conceptual progress. Instructional Science, 24, 125-155.

Palonen, T. & Hakkarainen. (2000). Pattern of interaction in computer-supported learning: A social network analysis. In B. Fishman & S. O' Connor-Divelbliss (Eds.), The Fourth International Conference of the Learning Sciences, pp. 334-339.

Romny, A. K., & Faust, K. (1982). Predicting information accuracy from patterns of recall among individuals. Social Networks, 6, 59-77.

Salomon, G. (1993). Distributed cognition. Cambridge: Cambridge University Press.

Scardamalia, M. (2002) Knowledge building principles. Unpublished manuscript, The Ontario Institute for Studies in Education, The University of Toronto: Knowledge Building Research Team.

Scardamalia, M., Bereiter, C., & Lamon, M. (1994). The CSILE Project: Trying to bring the classroom into World 3. In K. McGilley (Ed.), Classroom lessons: Integrating cognitive theory and classroom practice (pp. 201-228). Cambridge, MA: MIT Press.

Sfard, A. (1998). On two methphors for learning and the dangers of choosing just one. Educational Researcher, v27(2), pp4-13.

Stahl, G. (2000). A model of collaborative knowledge-building. In B. Fishman & O' Connor-Divelbiss (Eds.), Fourth International Conference of the Learning Science (pp. 70-77). Mahwah, NJ: Erlbaum.

Tabachnick, B.G., & Fidell, L. S. (2001). Using multivariate statistics. Allyn & Bacon A Pearson Education Company 160 Gould Street Needham heights, MA 02494.

Tapola, A, Hakkarainen, K., Syri, J., Lipponen, L., Palonen, T., & Niemivirta, M. (2001). Motivation and Participation in Computer-supported Collaborative Learning. In P. Dillenbourg, A. Eurelings & K. Hakkarainen (Eds.), European Perspectives on Computer-Supported Collaborative Learning. Proceedings of the First European Conference on CSCL (pp. 585-592). McLuhan Institute: University of Maastricht. Available:http://www.mmi.unimaas.nl/euro-cscl/Papers/159.doc.

Van Aalst, J., & Chan, C. (under review). A design experiment on knowledge building: virtual visits and pedagogical knowledge building principles. Submitted for review to journal of the Learning Sciences.

Van Aalst, J.C.W. (1999) Learning, knowledge building, and subject matter knowledge in school science. Unpublished doctoral dissertation, University of Toronto, Toronto, Ontario, Canada.

Wasserman, S., & Faust, K. (1994). Social network analysis: Methods and applications. Cambridge University Press.